MINUTES AND PROCEEDINGS
of the Thirty-third meeting of the
ARMED FORCES-NRC VISION COMMITTEE
November 12-13, 1953

Headquarters, The Armored Center

Fort Knox, Kentucky

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AGENDA OF THE 33RD MEETING
AND
INDEX TO THE PROCEEDINGS

ARMED FORCES-NRC VISION COMMITTEE

Minutes of the Thirty-third Meeting

November 12-13, 1953

Headquarters, The Armored Center
Fort Knox, Kentucky

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SOME ASPECTS OF TANK STEREOSCOPIC RANGE-FINDER PERFORMANCE*

Norman Willard, Jr. and Howard C. Olson
Human Research Unit No. 1, Ft. Knox, Kentucky

Foreword

The material presented in this paper is part of a larger study dealing with the training and selection of stereoscopic range-finder operators for Armor. Detailed results concerning the training and selection aspects of that study will not be presented here, but findings arising from the research do comprise the topics contained in this paper.

Introduction

At the present time, Armor is employing stereoscopic range finders in three models of tanks. The introduction of such an instrument into the tank has generated training and selection problems not unlike those faced during World War II. It will be remembered that previous research by the Army and the Navy has indicated that a relatively small percentage of the military population can satisfactorily operate a stereoscopic range finder. The number of instruments in Armor, the small crew per tank, and the high turnover in personnel makes it imperative that Armor have a large number of qualified stereoscopic range-finder operators available.

Purpose

The present study was conducted in an attempt to provide Armor with information about stereoscopic range-finder operation:

1. Minimum training time
2. Efficiency of training methods
3. Use of selection measures.

Subjects and Apparatus

For this study a sample of 120 enlisted men were retained at Fort Knox for a period of five weeks immediately following the completion of basic training. These men had had no previous training or experience with a stereoscopic range-finding instrument.

The range finder used in this study is the Army Model T41. This instrument has a base length of 60 inches, a magnifying power of 7.5, and is auto-collimating. Except for the auto-collimating feature, this instrument is very similar to the Navy Mark 63 range finder. The twelve instruments used in the experiment had been removed from the tanks, mounted on wooden frames, and housed in a building adjoining Godman Air Force Base.

Procedure

The research was conducted in four stages: (1) vision pre-testing, (2) classroom orientation, (3) range-finder drill, and (4) vision post-testing.

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*The authors wish to express their gratitude to Mr. Robert D. Arnold, who, while with HRU No. 1, OCAFF, assisted in the execution of the present research.

In the vision pre-testing phase, seven vision tests were administered to the trainees. After the first administration of the vision tests, the students were given a four-hour orientation lecture on the range finder, M12. This lecture included instruction on the characteristics, nomenclature, uses, operation, maintenance, inspection, and adjustment of the instrument.

Following the orientation lecture, all students began practical range-finder training. During this training, each student made 804 range settings. All rangings were made on six stationary land targets at the following ranges: 674 yards, 711 yards, 918 yards, 1100 yards, 1965 yards, and 2371 yards.

At the conclusion of range-finder training, the seven vision tests were administered.

Results

The present study has produced essentially the same results that were found during World War II with respect to training time and per cent of men who can effectively operate the stereoscopic instrument. Few men demonstrated improved ranging performance after 500 range settings. Only 25 per cent of the trainees approached the required proficiency standard.

Training method modifications, comparing knowledge of results and no knowledge of results, were not significantly different.

Three selection measures, consisting of subject variability in making interpupillometer settings, Army Classification Battery Aptitude Area VII, and an original test of stereopsis developed by the co-author, were found to have significant relationship will ranging performance. These measures yielded a multiple correlation of .53 with ranging performance.

Discussion

Thus far, the findings reported herein are quite routine. However, all has not been as simple as it has appeared.

In an attempt to establish a system of rating range-finder operator performance on targets of varying ranges, it was found that the traditional scoring unit was inadequate. The unit of range error used during World War II was the Unit of Error (UOE) described by the equation:

$$\Delta R = K(R)^2$$

where ΔR is an increment in range, K is a constant for a given base length, magnification, and binocular parallex acuity-value, and R is the range to the target in thousands of yards.

The UOE has a long history of valuable service to the Armed Forces. It was used during World War II to describe the performance of stereoscopic height finder observers and Navy range-finder operators. If one were to operate under the assumption that the minimum discriminable angle remained constant throughout all ranges, the equation given above would be correct. This relationship has been demonstrated to hold when the only cue to depth judgment is retinal disparity.

Whatever the scoring unit used, UOE or some other measure, there are two indices of the performance of an operator of the stereoscopic range finder. The first of these is mean-range error. It may be best described as the distance in yards between the center

of the distribution of range settings by an operator and the true target range. The mean range error may also be expressed as the angle between these two points. The second measure of performance is a variability measure taken from the distribution of an operator's range settings about the mean of his distribution. This variability measure may be a standard deviation, mean deviation, or arithmetic range. Any of these will adequately describe the variability of a range-finder operator, or the scatter of his range settings.

The Range Finder T41 includes an adjustment mechanism designed to eliminate the first of these performance problems. The Internal Correction purports to reduce mean range error to zero. This correction was calibrated in units equal to one UOE. This type of correction was introduced on the assumption that the mean range error was a constant angular value.

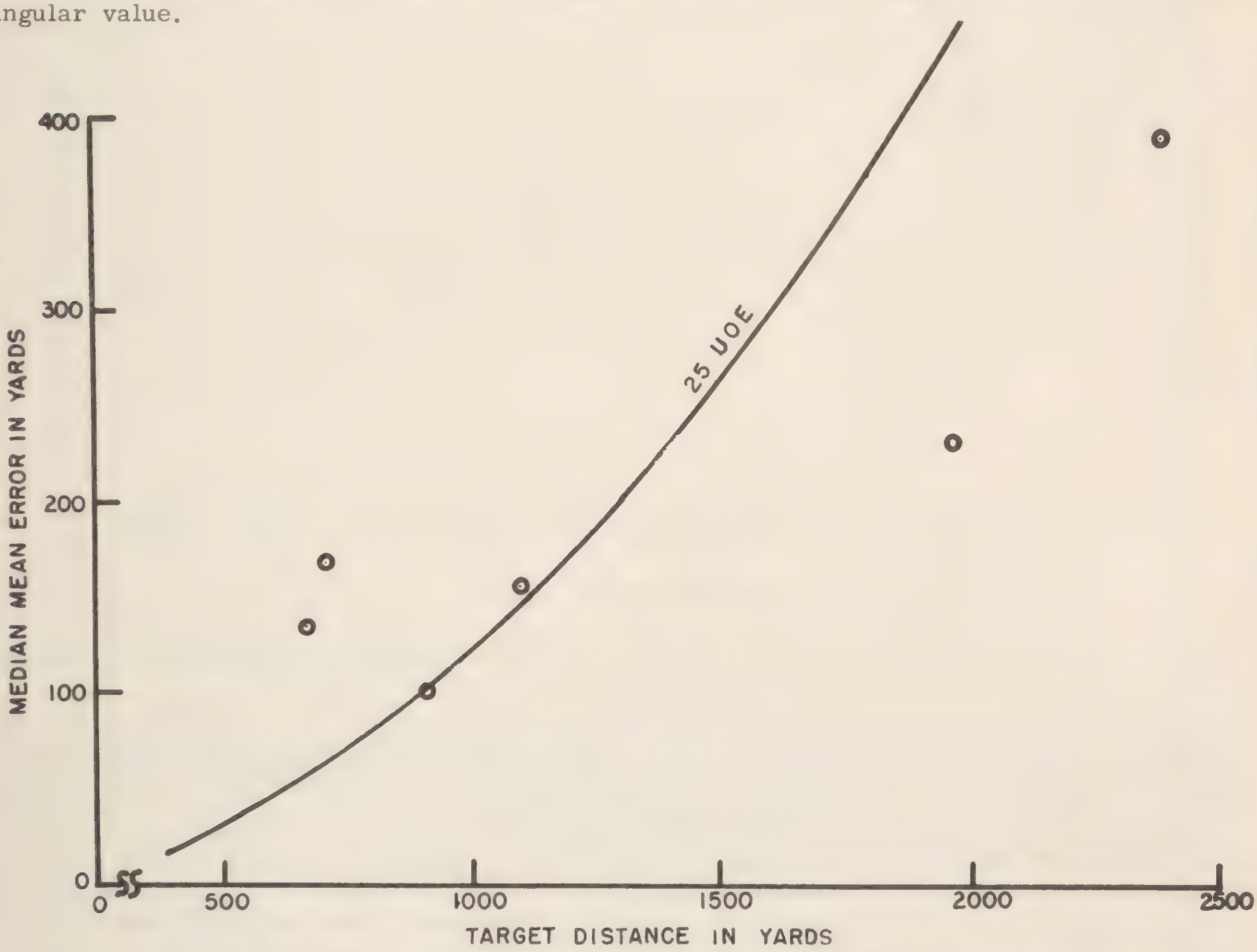

Figure 1. The relationship between mean error in range-finder settings and target distance.

In terms of range error in yards the correction followed the smooth, positively accelerated curve shown in Figure 1. The results of the present study indicate that range-finder operators do not perform according to this relationship. It will be noted that the points, representing mean range error in yards, are generally above the UOE curve at ranges less than 1000 yards, and below it at ranges beyond 1500 yards. These points represent the mean localization of the target by 110 independent operators. It appears, from the location of the points on this figure, that the UOE function does not best describe the relationship between the points. Therefore, it follows that a UOE, or ICS, correction applied to any one of the points will not correct for the other several target ranges. Further, it appears that the maximum permissible correction in yards, which is plotted here, is

insufficient at short ranges, appropriate at approximately 1000 yards for 50 per cent of the operators, and in excess at ranges beyond.

The smooth, rapidly accelerated function (25 UOE) describes the increment in yards of a constant angular value applied throughout target range. The points, however, indicate the localization threshold in depth is decreasing, when measured in angle, as a function of target distance. The decrease in the angular value as a function of range is shown in Figure 2. Note that in each figure the points represent the median value of the average performance for 110 range-finder operators.

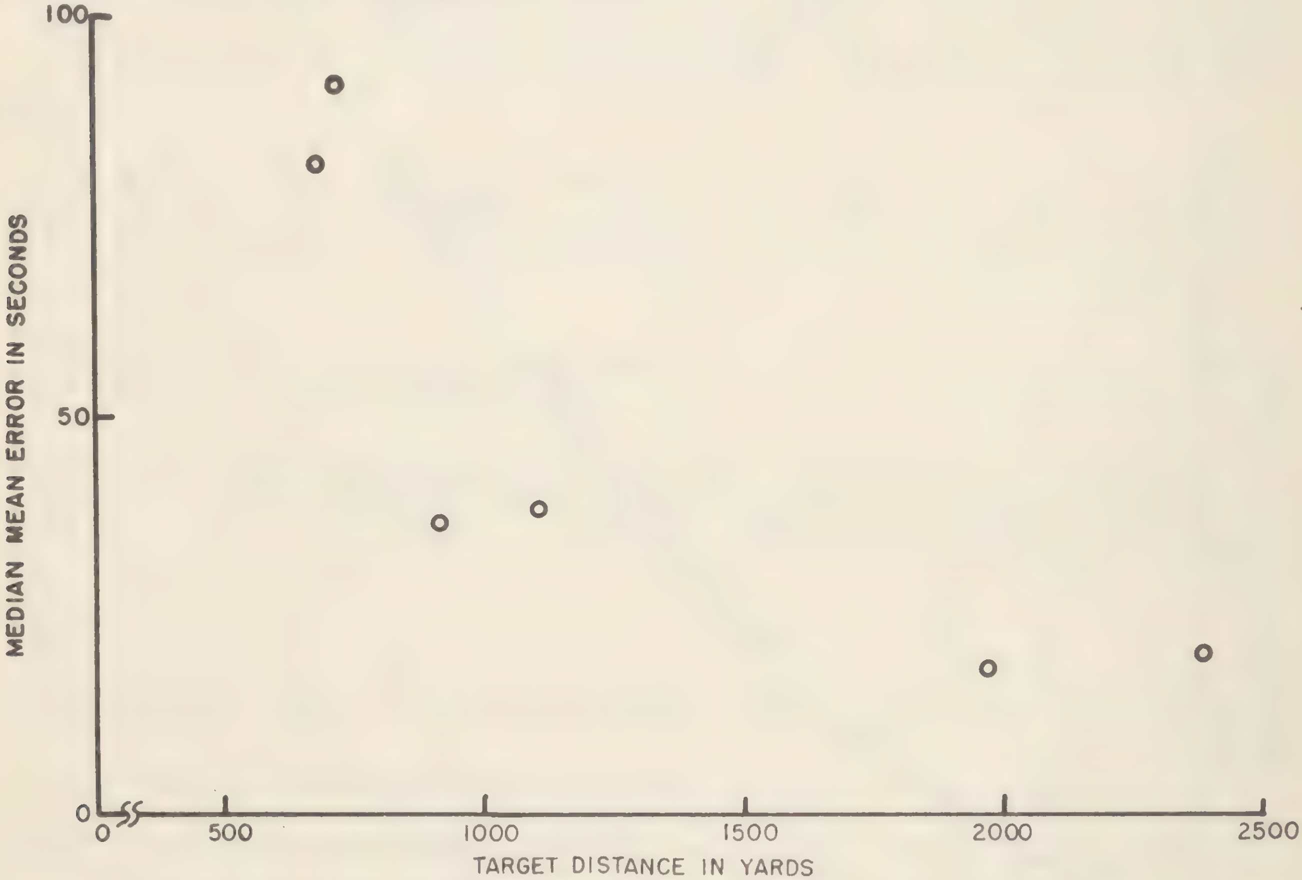

Figure 2. The relationship between mean error in angle in range-finder settings and target distance.

The second measure of range-finder operator performance used in this study was a variability measure. The standard deviation of each group of range settings by an operator was used. During World War II, a variability measure had been used in conjunction with the UOE concept previously described. Range settings were transformed to UOE values and the variability measure of the distribution of these UOE values was calculated. This is an appropriate technique, if the performance of the operators conform to the UOE curve. In the present study, variability in yards was demonstrated to be a linear function of target range. This is shown in Figure 3. Had the present investigators continued on the assumption that range-finder operator performance in the field situation conformed to the UOE curve, and had they thus transformed all range readings into UOE and from these units derived a variability measure, it should be readily apparent that very few men would appear proficient at ranges under 1000 yards and that a high percentage of men would appear proficient at ranges beyond 2000 yards. This appearance of a high percentage of proficiency at greater distances might lead to a false sense of security. The facts

of the matter are that approximately the same percentage of men are proficient throughout various target distances. This percentage, as demonstrated in World War II, is low.

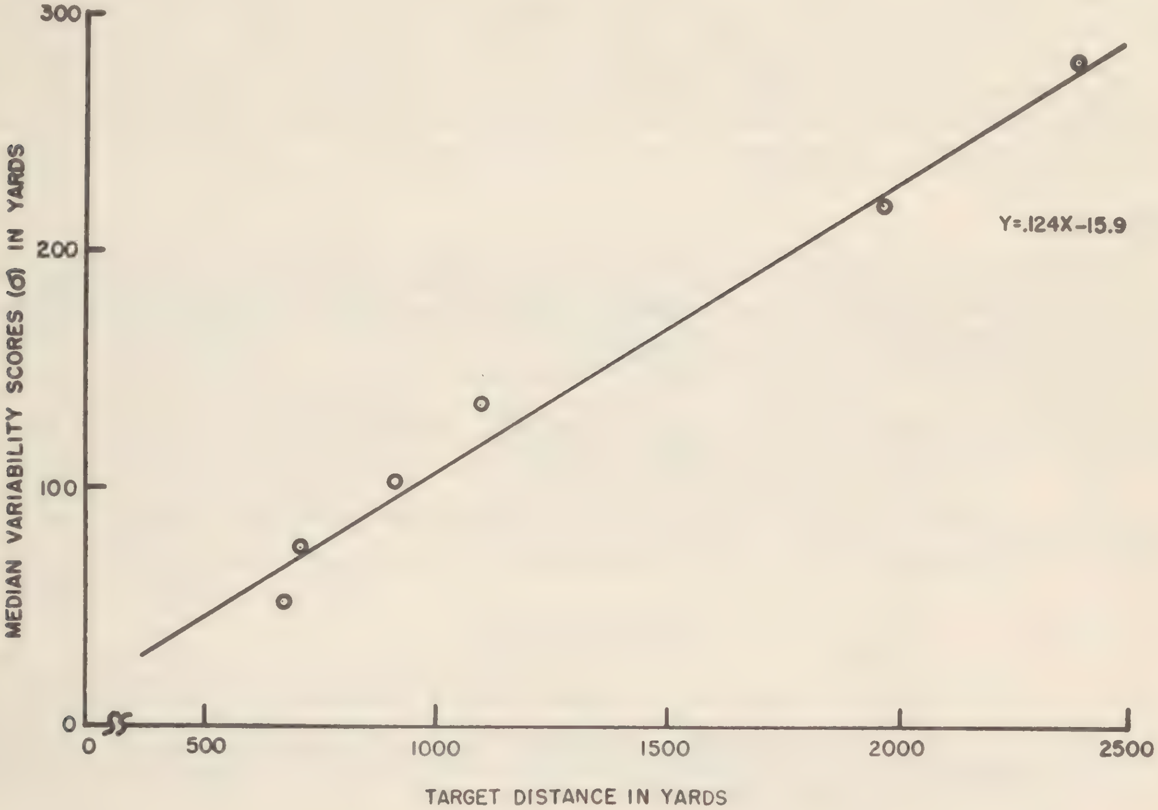

Figure 3. The relationship between subject variability in range-finder settings and target distance. Each point represents the median-variability value for 110 subjects.

As a result of the present findings, a new scoring system was developed which avoids the errors present in the UOE concept. This system uses the arithmetic range in yards as the index of operator variability, arithmetic range values being categorized into a series of proficiency classes. Using this scoring method, an operator's ranging performance may be judged in a matter of seconds. The value of any scoring technique will be low, however, unless the internal mechanism of the range finder permits an accurate correction for the individual operator's constant error. The present Internal Correction System, based on the UOE concept, does not do this effectively.

The findings of this experiment are not unique. In 1945 Holway and his colleagues (1) pointed out deviations from the constant discriminable angle hypothesis similar to those reported here today in a report entitled, Factors Influencing the Magnitude of Range Errors in Free Space and Telescopic Vision.

Implications

Since these findings indicate a serious defect in the present fire-control system, the authors are collecting additional information from another tank gunnery project. At the present time an intensive study of tank fire effectiveness is being conducted under the code name, Project STALK. This project is being conducted by the Ballistics Research Laboratory, and under the direction of the Department of the Army, Human Research Unit No. 1

is analyzing the performance of the 60 range-finder operators being trained for that project. The report of these results will be submitted about 1 February 1954.

These findings have immediate implications for changes in the present stereoscopic instrument. The instrument has a constant angular correction for the reduction of mean-range error. Since mean-range error is not a constant angular value in the field situation, but is, rather, a decreasing angular value with target distance, the present "correction" is introducing error into the operator's performance. Since operator variability in yards is an increasing linear function of range, any scoring system based on the Unit of Error concept is giving the user a false picture of operator performance.

Conclusions

1. This study had indicated that, when a stereoscopic range-finding instrument is used in the field situation with a heterogeneous background which permits other depth cues in addition to retinal disparity, the mean localization of the target becomes more accurate, in terms of angle, as a function of target distance.

2. This study indicates that operator variability in yards, about the point of mean localization, is a linear increasing function of range.

3. From conclusion 2, it is deducible that range-finder operator variability in terms of angle, is a decreasing function of target range.

REFERENCES

1. Holway, A. H.; Jameson, Dorothea A.; Zigler, M. J.; Hurvich, L. M.; Warren, A. B.; and Cook, E. B. Factors influencing the magnitude of range-errors in free-space and telescopic vision. Boston: Division of Research, Graduate School of Business Administration, Harvard University, August 10, 1945.

2. Summary Technical Report of Division 7, NDRC, Volume 2: Range finders and tracking. Washington: Office of Scientific Research and Development, 1947.

Discussion:

Mr. Adkins asked what percentage of operators could use the rangefinder satisfactorily.

Mr. Olson answered that 25% approached satisfactory performance.

Col. Smith wanted to know what standard was rated as satisfactory.

Mr. Willard explained that their standard for satisfactory performance was twice the standard used by the Navy and the Aircraft Artillery School during World War II. He thought the use of the stereo rangefinder was more limited in armor. The actual standard being used is a value equivalent to 4 units of error at a range of 2,000 yards.

Col. Hammack asked how much better the remaining 75% of the operators were at getting first-round hits than if they had no rangefinder at all.

Mr. Willard said this was an excellent question. He regretted that they did not have any basis for an answer to this question in the present study, but thought that Project Stalk would provide that information.

A SUMMARY OF THE DISCUSSION OF THE GENERAL PROBLEMS OF STEREOSCOPIC ASPECTS OF VISUAL DEVICES USED FOR TANK FIRE CONTROL

Dr. Blackwell called for comments on the demonstrations of tank fire-control devices attended by the Committee.

Dr. Sloan commented upon the possible practical value of the use of a succession of short exposures to facilitate stereoscopic judgments in tank rangefinders, referring to the remark made by Dr. Ogle as to relative efficiency of the short and long exposures in eliciting stereopsis. Dr. Sloan also commented on the fact that apparently some rangefinder operators prefer to displace the reticle laterally from the target. Such a use of the reticle introduces constant errors in ranging due to lateral aniseikonia. These operators have difficulty with terrain obstacles in some instances and are then forced to relocate the reticle vertically displaced from the target. The range error due to lateral aniseikonia is not present under this latter condition.

Dr. Sloan also expressed the belief that an improved method for setting the interpupillary distance should be devised.

Dr. Fry expressed interest in the importance of accuracy in ranging with flat trajectory missiles such as those fired by tanks.

A comment was made from the audience that stereoscopic range accuracy is necessary because the missiles do not have as flat a trajectory as might be desired.

Dr. Carlson stated that he felt obligated to make an extensive comment on the Holway paper, since reference had been made to this paper in informal conversations during the fire control demonstration. Dr. Carlson noted that most members of the Vision Committee seemed to be familiar with one section of Dr. Holway's paper, a section concerned with ranging under "conditions of commonplace vision", or something of that sort. Dr. Carlson emphasized that these experiments were conducted under conditions which do not apply to stereoscopic rangefinding as it is commonly carried on in military optical instruments. The Holway experiments concerned ranging acuity with two cards, one of which was arbitrarily designated as the reticle, the other designated as the target. These cards were identical and were known to be identical by the observers. Thus, the observers were able to utilize apparent size as well as other cues for depth perception. Holway's experiments were conducted at ranges varying from a few inches indoors to thousands of yards in open space. The unaided eye and various optical magnifiers were studied. Holway found that values of ΔR, the incremental ranging error, did not vary proportionally with the square of R but rather with the 1.25 power of R. Dr. Carlson commented on the small amounts of convergence present under the conditions of the Holway experiments. In fact, Holway was able to obtain depth discrimination down to a few thousandths of a diopter, a situation where the sensitivity of discrimination far exceeds the precision of interferometry, so far as detecting the wave front phase is concerned. This means that the depth discriminations cannot depend on wave front deformation. Dr. Carlson expressed his belief that the role of size cues was obviously important under these conditions.

Dr. Carlson emphasized that, in his opinion, the Holway results do not have relevance to optical rangefinding, where size cues are of comparatively little value.

Dr. Fry asked for information on the current classification on the Holway report.

Dr. Carlson stated that to the best of his knowledge the report is Restricted and has never borne a higher classification.

Dr. Sloan stated that she believed the Holway report to be unclassified.

Dr. McGuigan remarked that the discussion had made apparent one of the problems faced at the Human Resources Research Office, namely, the problem of stereo rangefinder training. The important discovery for those concerned with operational problems, and certainly for the people in armor, is that it has been found that a large percentage of men do not have the necessary ability to use the rangefinder. This phase of the investigation is near completion and further projects are planned to attempt to develop methods which might train each man more effectively, or train more men to use this stereo device. Dr. McGuigan said that his group would be very much interested in getting suggestions from those present at the Vision Committee meeting. He put the following question to the group: "If you were attempting to train a man to use the stereo rangefinder, how would you go about it?"—and invited anyone who had ideas on this subject to communicate with him.

Dr. Blackwell noted that the correlate to the problem of training men to use the stereo device is the problem of the design of the stereo rangefinder. He wondered if it would be worth while to continue the discussion, with comments on the design question.

Dr. McGuigan replied that, since the device is now in operational use, it is a training problem so far as his group is concerned. He considered the design a future problem, with the training problem of prime importance at this time.

Col. Hammack, of the Weapons Department of the Armored School, related to the Committee some of the difficulties experienced with students being trained to use the rangefinder. He said that for the last three years about 10,000 students per year have come through the Weapons Department. When the rangefinder is talked about, the first difficulty is the word "stereo". When "stereo" is mentioned to a non-com class, their answer is, "Well, I don't have that." For this reason, the expression "seeing in depth" has been adopted. Col. Hammack stressed the importance of showing the man just what he is supposed to see, rather than simply trying to explain it to him. This is done by means of stereo slides which students view with polaroid glasses.

Col. Hammack pointed out another factor which he had discovered in his 27 years of service: A soldier will always do things the simplest way. Given a choice of sights, the chances are that, unless he is thoroughly trained, he is going to use the simpler sight. A man must be so thoroughly trained in the use of the rangefinder that he has confidence in it, or he will not use it. Also, his superior officers must be convinced that the rangefinder is good, for if the officers are not sold on a particular device, it is extremely difficult to get the men in his unit to learn to use it.

Col. Hammack went on to say that the Weapons Department was convinced that, in order to get a large percentage of first-round hits, some instrument to assist in getting the range to the target is absolutely essential. Although they are using the stereoscopic rangefinder at the present time, they do not consider it the ultimate in rangefinders and hope before too long to have something much better and much simpler.

Col. Hammack said that he was glad to hear the comments stating that short exposures of a target enhanced stereoscopic vision, for they now teach their trainees that they must range on a target within 5 seconds. The trainees are also taught to concentrate

on the target, rather than to try to follow the reticle as it moves out or back. Both of these points help a great deal in teaching the use of the rangefinder.

Mr. Anthony said that during the tank demonstrations he had noted two possible sources of shimmer: the convection currents in the line of sight arising from the earth's surface during a hot day, and the convections arising from the hot exhaust to the rear of the tank when the operator is facing in the aft direction. He wondered to what extent shimmer disturbances through each objective of the stereoscopic ranger influence stereoscopic ranging.

Col. Hammack answered that shimmer does have some effect. Reports have come from Camp Irwin, California, where it is very hot, that radiation off the tank and radiation from the ground have been causing trouble. However, Colonel Hammack had no specific information as to the extent of such difficulties.

Dr. Imus offered several comments on training. Referring to work done with the anti-aircraft artillery and with the Navy anti-aircraft during the war, he stated that it had been found that intensive practice is essential and that the men must be trained to operate the rangefinder in practice in exactly the way they would be expected to operate the rangefinder under fire.

Dr. Imus also mentioned that, during wartime training, they had attempted to use the Mark II rangefinder trainer as a predicter of how the men would perform after the three months' course in rangefinding. They found that the Mark II did not predict that; however, it would predict how well the man would be doing one week hence.

Dr. Imus concluded his remarks by voicing approval of the Ft. Knox people's interest in breaking away from tradition and experimenting with new methods.

PROPOSED STUDIES ON THE EFFECTS OF FLICKERING LIGHT ON THE HUMAN SUBJECT

L. M. N. Bach
Department of Physiology
Tulane University

While unpleasant sensations have long been associated with intermittent light, the history of such effects has largely been anecdotal. The principal method of investigating these effects has been the use of the critical frequency for fusion (C.F.F.) in which a rotating sectored disc interrupts a light source. Unusual subjective effects derived from this technique are generally limited to apparent movements or colors which are not inherent in the physical procedures used.

In recent years electroencephalographers have developed and utilized a method termed "PHOMAC" for the purpose of eliciting the electroencephalographic patterns characteristic of petit-mal epilepsy in those cases which were suspect from their history but did not evidence the usual electrical patterns spontaneously. The PHOMAC method involves the use of flickering light together with a simultaneous intravenous injection of metrazol, a convulsant drug. In the induction of the pathologic electrical effects, it was found that their elicitation was more effective when the flicker frequency of the light was triggered by the dominant frequency of the spontaneous electrical rhythms of the brain (electroencephalographic waves).

Other workers, namely Walter, Gastaut and Mundy-Castle have found that flickering lights of high intensity, without the concommitant use of metrazol, by themselves caused a wide variety of unpleasant subjective reactions; these effects seem particularly pronounced when the flicker frequency is triggered by the dominant electroencephalographic frequency.

The light intensities used have varied among investigators. Some have used photofloods, and values such as 3-12,000 footcandles, 88,000 candles, a 400,000-footcandle strobotron, and an 8,000,000-candle (200,000 estimated at retina) strobolume have been reported. The importance of using a silent red-orange neon rather than a clicking blue-white xenon source has been pointed out. Usually the incident intensity is measured with a photocell mounted between the subject's eyes. The distances of the light sources from the eyes vary from 3 feet to 18 inches to 1 foot to a "few centimeters." Flash durations vary as follows: .001 sec., .005 sec., .015 sec., and one investigator specified 15-second intervals between flashes.

The frequencies used are often determined by the dominant EEG frequency which is selected by a frequency analyzer and amplified to operate an electronic switch which in turn activates the light source. These frequencies vary between 5-15 per second usually although they may go as high as 100 per second. Frequencies which elicit either subjective phenomena or abnormal EEG activity may vary from one individual to another and within the same individual, but dominant frequency triggering seems to be more consistently effective. The wavelengths used have not been too specifically described but usually a blue-white xenon lamp is used. Recently, orange-neon lamps have been used and better effects have been claimed for it. It has further been claimed that the effects are exaggerated by eyelid closure because only red light gets in under these circumstances. In the PHOMAC effect, however, red filters are said to increase the threshold, decrease the duration, increase the latency, and in petit-mal subjects it is claimed that red goggles reduce the number of convulsive episodes. In the CFF effect it has long been known that

rod insensitivity to red makes this wavelength ineffective at low levels of illumination and that the shorter wavelengths become increasingly effective in the dark-adapted eye.

The subjective effects of flickering light triggered by the dominant EEG frequency are as varied as the number of investigators and the variety of conditions used. Some claim that effects are rarely encountered and a lot depends on psychic suggestion (Bickford, Brazier). Others vigorously claim universal effects on normal subjects (Walter, Mundy-Castle, Gastaut). Walter particularly has described a variety of effects as follows:

> Visual sensations not in the visual field originally, variegated colors, visual patterns, kinesthetic sensations of swaying, movement, dizziness, vertigo, spinning, jumping, tingling, prickling, fatigue, confusion, fear, exhaustion, disgust, anger, temporal or spatial disorientation, emotional upsets and organized hallucinations. These latter may be so vivid as to last for a week.
>
> Intensification of the illusions occurs with eyelid closure and irritation is increased with concommitant emotional upsets. Especially disagreeable effects are obtained when the frequencies are changed especially between 5-7 or 10-4 c.p.s. The effects are enhanced in young individuals or those showing theta EEG waves (a frequent sign of psychological immaturity) and in those instances of pre-existing tenseness or irritability or where there is a low blood sugar, increased ACTH blood levels (due to stress); also the use of red lights, visualization of the flicker and various psychological states are exaggerating factors.

The mechanisms of these effects have been debated. Some feel that the unpleasant subjective phenomena are due to pupillary and accommodative drive. This seems to be apparent in the C.F.F. studies where obvious ocular tension occurs when the flicker is just changing to a steady light, specifically where the dark phase is changing to a shadow phase. It was thought by some that failure of the optical systems to respond to the flicker frequency was the basis of fusion but Halstead showed that paralysis of these mechanisms did not affect the phenomenon. Edgerton actually stabilized pupillary size to 6 mm. with eucotropine in the triggering phenomenon so it seems unlikely that driving of the pupil and ciliary mechanisms are significantly involved.

More recent ideas center on rhythmic photic interruption of basic scanning rhythms in the brain which are vital for consciousness. The existence of such reverberating (scanning?) circuits have recently been postulated on experimental evidence and we hope to investigate this phenomenon more fully. We propose to determine systematically in the laboratory the following limitations to the field use of the unpleasant effects of flickering light on the human subject. Those parameters of wavelength, flash duration, frequency, variation in frequency, intervals between flash series, psychological states, physiological states, and light intensity which fit most consistently in a distribution curve of a normal young male population will be determined. The basis of this proposal lies in the use of the flicker method to produce unpleasant effects consistently enough to render ineffective a significant number of the type of personnel to be expected in the field.

A BRIEF SUMMARY OF PROJECT MICHIGAN

John Strand
University of Michigan

Early in 1952, as the result of studies such as Projects VISTA and BEACON HILL, and the report of the BEACOM Mission to Korea, it was concluded that prompt action should be taken to reduce the discrepancy that exists between the striking potential of our military weapon systems and our capability of providing proper targets for these systems. These considerations gave rise to the Battlefield Surveillance Program. In August 1952, the TEOTA (The Eyes of The Army) Study was initiated. The purpose of this study was to determine the status of those current and required systems, techniques, and equipment which might be applicable to Battlefield Surveillance. Included were: television, thermal-detection, radar, optical and acoustical devices. The Project TEOTA study group included over 100 outstanding scientists and engineers from industry, universities, and other government departments, as well as military representatives. A detailed examination was made of the military requirements, as well as known and possible future technical systems and devices applicable to Battlefield Surveillance. Two major recommendations stemming from Project TEOTA were as follows: First, that a major research and development program be initiated, integrating all physical methods applicable to Battlefield Surveillance; and second, that this program be carried out on a continuing basis under the auspices of a suitable university. The TEOTA group recommendations were implemented last spring, when a contract was let with the University of Michigan and the over-all project redesignated Project MICHIGAN.

Project MICHIGAN has been in existence since May of 1953. The first three months were spent in preparing for the project and in carrying out a summer study called Project WOLVERINE. Since the completion of the summer study in September, planning of the broader aspects of the project has continued along with implementation of the recommendations of Project WOLVERINE. Project MICHIGAN is endorsed by the three services, under contract to the Department of the Army, and administered from the Office of the Chief Signal Officer.

Battlefield Surveillance can be defined as the all-weather surveillance by any technical means of the region extending approximately 200 miles beyond the main line of resistance, and the over-all system required to correlate and apply, rapidly and effectively, the information derived from this surveillance. The main functions to be performed under the project are: The carrying out of over-all system study; the performance of research, both at the University of Michigan itself and under subcontract at other qualified organizations; the coordination of the research and development program in Battlefield Surveillance throughout the country; the recommendation to the military of means for filling gaps in the research and development program; the conduct of tests at the University of Michigan and aid to the military in the preparation and conduct of tests in the field on Battlefield Surveillance devices; and the advising of the military on the final procurement of devices and systems for Battlefield Surveillance.

It was realized by Project MICHIGAN at the outset that it was desirable to begin at once a program in research and development. It was for this purpose that a planning project of short duration, Project WOLVERINE, was set up. The mission of Project WOLVERINE, therefore, was to review existing research and development programs and to recommend to Project MICHIGAN an initial program in research. The project was carried out by some fifty scientists and associated military personnel working at the University during the past summer. These fifty scientists were divided equally between the University

of Michigan and those from other organizations. Those from other organizations were about equally divided among industrial scientists, scientists from military laboratories, and scientists from other universities. The major results of Project WOLVERINE were as follows: A broad recommendation for carrying out the entire project, some procedural recommendations covering the conduct of the project, and twenty-three specific recommendations for research and development. At the outset of WOLVERINE its Steering Committee realized that it was desirable to be concrete in the choice of a program and to limit the number of problems considered because of the short duration proposed for the summer project. They therefore selected four major problem areas. They believed that these four major problem areas would be on anyone's list of most important problems, although not necessarily at the top of everybody's list. The first of the areas considered was Increasing the Effectiveness of the Individual Combat Soldier, which became generally known during the summer as Aids to the GI. This first area was further broken down into three parts: Methods for giving the individual combat soldier the ability to communicate with his neighbor; methods for keeping better track of the positions of friendly troops; and methods for improving his ability to see at night. The second major problem area considered was that of Detection of Concentrations. Concentrations were taken to be collections of troops, tanks, trucks, ammunition dumps, and artillery. This particular area becomes much more important with the advent of area type weapons. The third problem area considered was that of Preparation of Terrain which is the attempt to establish remote listening or seeing posts. The final area considered was that of Data Processing.

In all there were twenty-three specific recommendations of Project WOLVERINE; at the present time Project MICHIGAN has initiated action on some fifteen of these recommendations. Concerning Aids to the GI, Project WOLVERINE recommended to Project MICHIGAN the study and further development of the evaporograph, a thermal imaging device, and the development of tables, similar to artillery tables, for the better use of searchlights. It was recommended further that development be undertaken on a portable searchlight and a microwave floodlighting system; that the need for communication of the individual combat soldier with his neighbors in the front lines be evaluated and, if necessary, a communication system for the same purpose be developed; and that the possibility of using presently available beacons to enable our own forces to better maintain a knowledge of their own troops in hilly terrain be studied and tested.

Under the area of Detection of Concentrations the recommendations were for the study of the use of circular polarization radar, improvement of airborne radar, the evaluation of the military need for TV, the development of acoustic devices for detection of concentrations, and the possibility of development of infrared detectors in the three to fourteen micron range. Project WOLVERINE also recommended the further study of infrared backgrounds, the study of the application of microwave techniques to Battlefield Surveillance, the study and investigation of the methods of improving the dynamic range of radar displays, the use of low frequency, ground-based doppler radar to determine whether this would be a feasible technique of detecting large moving concentrations, and the development of instrumentation in micrometeorology.

In the third area, Preparation of Terraine, there was one recommendation which was broken into five parts. This is the recommendation for the development of a relatively self-contained system for the establishment of a remote listening post. This system would be composed of sensory devices to be placed in enemy terrain. (Project WOLVERINE concluded that the most useful of these would be in the acoustic and seismic field and recommended development of such devices.) In addition they suggested study of other techniques for detection. They recommended the study of the acoustic signature of military targets; the study of acoustic and seismic transmission characteristics in air and ground; and to tie all of this together, the study of information-handling techniques associated with the system.

Finally, in the fourth region of Data Processing, Project WOLVERINE made a general recommendation to study the assembling, transmission, editing, storage and display of information which is traveling in military channels on the battlefield.

Project WOLVERINE has completed its deliberations and its report has been published. Requests for copies should be made through the Office of the Chief Signal Officer.

In addition to implementing a research and development program in Battlefield Surveillance, Project MICHIGAN: is actively engaged in carrying out surveys of present and proposed systems and devices that apply to the problem; is participating in field exercises and maneuvers to test the performance of the present system and to determine possible lines of improvement; and is attempting to determine the parameters of a Battlefield Surveillance system which will give our fighting forces an increased surveillance capacity in the near future.

REPORT OF WORKING GROUP ON A-O VISION TESTING DEVICE

Benjamin J. Wolpaw, M.D.

An organization meeting of the working group was held on May 7, 1953 at the Wilmer Ophthalmological Institute, Baltimore, Maryland.

In order not to burden any one group of workers to an excess, the project was subdivided as follows:

1. A-O vs. Wall Chart
   - (a) Medical Research Laboratory
New London, Connecticut
   - (b) A.G.O. Office--Personnel Testing Section
2. A-O vs. Armed Forces Vision Tester (B&L)
   - (a) School of Aviation Medicine
Pensacola, Florida
   - (b) School of Aviation Medicine
Randolph Field
3. Test -- Re-test on A-O device
Human Resources Group #1
Fort Knox, Kentucky

On November 11th, 1953, the entire working group met again at Fort Knox. Although the data have not been assembled in final form, the results obtained by all of the collaborators were strikingly uniform. Based upon the data obtained, it must be concluded that the device as presented to the working group is not satisfactory. This was true particularly with regard to visual acuity which did not meet requirements.

The statistical data will be presented by each sub-working group as a separate report and the final resume will be presented to the Vision Committee in the near future. The various workers on this project are to be complimented for the completion of their task in so short a time.

REPORT OF THE WORKING GROUP ON NIGHT VISION TESTING

E. Parker Johnson, Chairman

The present Working Group on Night Vision Testing is a very small group engaged in work on a very specific problem. In 1951 the Personnel Research Section in the Adjutant General's Office of the Department of the Army was interested in the possibility that "Night Vision," which had proved so difficult to test at scotopic, or "starlight," levels, might prove more amenable at "mesopic" or, roughly, "moonlight" levels. It was thought that the simplification of the testees' visual task, which would now approximate more closely to that of day vision--in that inspection of visual targets would be carried out foveally—might improve test reliability.

An additional point presented in favor of the mesopic level was that it might cut down on the time required for pre-test dark adaptation. It was felt that adequate adaptation might be obtained in somewhat less than the half-hour minimum imposed by scotopic testing.

The objection that one might not, in working at mesopic levels, be testing the same capacity as that involved in scotopic work was met by the observation that the pertinent criterion for determining the validity of a test for visual components of night-soldiering is not another vision test—even if it be a scotopic one--but rather some visual aspect or aspects of night operations.

The Adjutant General's Office requested that the Vision Committee appoint a Group to sit with them, in an advisory capacity, beginning in the planning stages with discussion of test procedures and instrumentation and following through during determinations of reliability and, finally, of validity.

The Working Group appointed consisted of Dr. Louise Sloan Rowland, Dr. Austin H. Riesen, Dr. H. Richard Blackwell, and Dr. E. Parker Johnson, Chairman. The members of the Working Group met with personnel of the Adjutant General's Office in January of 1952 and discussed plans. It was decided that the Armed Forces Vision Tester might be modified for use at mesopic levels. Dr. Blackwell undertook the task of providing the instrument with a field of uniform luminance, a calibrating attachment, and filters to enable testing to be carried out provisionally at three levels in the scotopic--mesopic range. The machine was returned to the Adjutant General's Office where research has been conducted to determine test-retest reliability and the effect of adaptation procedures on levels of performance.

An informal meeting was held at Wright-Patterson Air Force Base in November of 1952 with validity criteria as its main topic. It was agreed: that men, in various numbers and attitudes, should be the visual targets—men being realistic military objects and, at the same time, familiar objects, so that perceptual skill would be relatively uncontaminated by the residue of previous military experience of the men being tested. It was agreed that there should be as little artificiality about the criterion tests as possible. This meant working outdoors at night, but it seemed necessary to have sufficient realism to make the criterion meaningful to operational personnel.

As it turned out, the validity trials were eventually made, this past summer, in conjunction with a project of the Human Resources Research Office of George Washington University. HumRRO personnel at Ft. Benning were conducting outdoor night exercises very similar to those planned by the Adjutant General's Office. Vision tests were thus

administered to some 300 of HumRRO's group of subjects. As chairman of the Working Group, I was able to attend a portion of the trials. The data collected are being worked up by the Adjutant General's Office staff and will, I presume, be presented to the Vision Committee in due course. I shall not attempt to suggest the conclusions at this time. I will only say I am hopeful that the data at hand will be sufficient to decide on the value of continuing research on mesopic testing.

SUMMARY

of a

DISCUSSION OF THE ARMED FORCES CLINICAL ACUITY CHARTS

Colonel J. H. King, Jr.
Walter Reed Army Hospital

Certain features of the Armed Forces Clinical Acuity Charts (far vision) recommended by the Vision Committee several years ago at the request of the Armed Forces appear undesirable. These may be enumerated as follows:

1. The large number of letters on the charts—four 20/20 lines with a total of 40 letters, 20 letters in the 20/30 line, etc.;

2. The absence of a 20/60 letter (which is required by the Army) and of a 20/400 letter;

3. The fact that the charts are printed on both sides, making it necessary to use two charts mounted side by side and thus increasing the cost as well as the inconvenience;

4. The fact that the charts are too large for use with the standard wall illuminators;

5. The fact that the charts involve so many printing difficulties that procurement is impossible; and

6. It was not clear whether the charts were to be used for screening refractions.

I have discussed the charts with Dr. Berens and several of the members of the Vision Committee who worked on the design of the charts. It was decided that a working group should be formed to formulate a new clinical chart using these same letters, which are very good, and also a new chart for screening purposes. I hope that the new committee will be able to meet very soon.

Discussion:

Dr. Berens requested that the Vision Committee members forward any criticisms or suggestions they might have to Colonel King without delay, since his group must get something done at once.

Dr. Sloan defended the inclusion of the four 20/20 lines on the chart, saying that they had been put there because people had asked for them. She went on to say that it seemed unfair to the Committee to imply that they did a lot of things that were not practical, since the specifications for the charts were drawn up by the service people who were going to use them.

CDR Farnsworth pointed out that the charts under discussion were meant only for clinical use; at no time were they meant for screening purposes. He said that he had objected to the selection of these charts, because he had been sure it would be misunderstood that they were to be wall charts for screening purposes. He noted that

the long-accepted visual screening methods say, "A chart will be recommended by the Vision Committee...," which caused universal misunderstanding by people who were not in on the early discussions of the clinical charts that these must be the wall charts for screening. CDR Farnsworth emphasized that the charts under discussion were never meant for wall charts and that a proper investigation to find out what those wall charts should be has never been carried out.

ARMED FORCES-NRC VISION COMMITTEE

ANNOUNCEMENTS

1. Dr. Conrad Berens, Acting Chairman, announced that the Committee Chairman, Colonel Victor A. Byrnes, had found it necessary to submit his resignation from this post, because of having been assigned to overseas duty.

Dr. Berens then read a resolution regretfully accepting Colonel Byrnes' resignation and honoring him for his long service and his many contributions to the Committee. This resolution was unanimously passed by a rising vote of the Committee. The text of the resolution follows:

> WHEREAS Colonel Victor A. Byrnes, USAF, has served as Chairman of the Armed Forces-NRC Vision Committee for three and one-half years and has performed all duties of this office with unusual devotion and great efficiency and tact;
>
> WHEREAS, due to his recent assignment to overseas duty, Colonel Byrnes can no longer serve as Chairman;
>
> THEREFORE, be it resolved that the members of the Armed Forces-NRC Vision Committee accept his resignation with deep regret;
>
> FURTHER, be it resolved that the members of the Committee express their great appreciation of the fine contribution Colonel Byrnes made to the work of the Committee in studying visual problems of the Armed Forces.

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2. It was announced that Dr. Conrad Berens had been elected to serve as Committee Chairman during the remainder of the present term, with Colonel J. H. King, Jr., as the Deputy Chairman.

RELATIVE VISUAL DIRECTION AS A FACTOR IN DEPTH PERCEPTION IN COMPLEX SITUATIONS

Walter C. Gogel
Army Medical Research Laboratory
Fort Knox, Kentucky

This paper is concerned with the application of two hypotheses to situations which, because of movement in the visual field, are more complex than the situations in which they were first demonstrated (2, 3). Both of the hypotheses involve visual direction. The visual direction of an object as it is used in this paper can be specified by drawing a straight line to the object from the observer's eye or from a point between the observer's eyes. If the angle formed between the visual directions of two objects is small, the difference between the visual directions of the two objects is small. If this angle is large, the difference between the visual directions of the two objects is large. The first hypothesis concerns binocular vision and can be stated as follows: A binocular depth illusion will least disturb the perception of the physical relative depth position of a binocular test object with respect to that part or object of the illusion which has the smallest difference in visual direction from the test object. The second hypothesis is most readily demonstrated when part or all of the visual field is monocular. It can be stated as follows: There is a tendency to see two (or more) objects as located at the same distance from the observer, with the strength of this tendency being inversely related to the difference between the lateral visual directions of the two objects. For purposes of illustration, the results from an experiment involving these hypotheses will be presented.

Experiment I

The display is illustrated by Figure 1. Two "seven of spades" playing cards were presented at the same time at a distance of 10 feet from the subject. The card on the left (object A in Figure 1) was a double-sized playing card (7 in. by 4-1/2 in.), and the card on the right (object B in Figure 1) was a half-sized playing card (1-3/4 in. by 1-1/8 in.). The centers of the two cards and the subject's eyes were all at the same height from the floor. The inner edges of the two cards were laterally separated by 9 inches. A small white disc (3/8 in. in diameter) was placed between the two cards with the center of the disc at the same height as the centers of the cards. The disc was placed in one of three lateral positions. These alternative positions are indicated by the dotted lines of Figure 1. The center of the disc was either a) 9/16 in. from the right edge of the left card (position 1 of Figure 1), b) 4-1/2 in. from both the right edge of the left card and the left edge of the right card (position 2 of Figure 1), or c) 9/16 in. from the left edge of the right card (position 3 of Figure 1). The distance of the disc from the subject (as shown in the top view of Figure 1) in all three lateral positions was the same as that of the cards. The brightness of the disc in each of the three lateral positions was equated to that of the white portions of the playing cards (2.2 foot-lamberts). No objects were

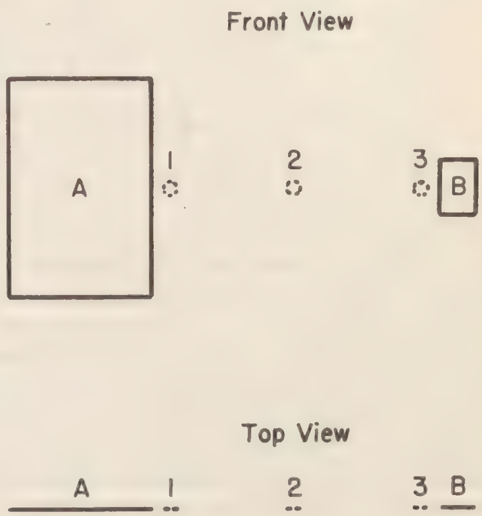

Figure 1. Conditions for Investigating the Apparent Depth Position of a Disc as a Function of its Lateral Position Between Two Differently Sized Similar Objects.

visible except the disc and the two playing cards. Both monocular and binocular vision were used for viewing the two cards and the disc. The order of presenting the various situations was varied between subjects with respect to (a) whether the binocular or monocular view was presented first, and (b) the order of presenting the three lateral positions of the disc.

Twelve men were used as subjects. Each subject was presented with each of the three lateral positions of the disc under each of the two viewing conditions. The task of the subject was to estimate in inches the apparent depth between the cards and the apparent depth position of the disc with respect to each of the cards. The average report of the subjects was that the right card was 18 inches behind the left card with binocular viewing, and 36 inches behind the left card with monocular viewing. The average reports involving the disc are given in Table 1. The first hypothesis is illustrated by the binocular results of Table 1. As the disc was placed laterally farther from card A and laterally closer to card B, the results changed from an average report of no depth difference from A and 20 inches in front of B to an average report of 18 inches behind A and 1 inch in front of B. The disc was physically always at the same distance from the subject as card A and B.

TABLE I

AVERAGE APPARENT DEPTH POSITION OF THE DISC AS A FUNCTION OF IT'S LATERAL POSITION BETWEEN THE TWO DIFFERENTLY SIZED PLAYING CARDS A AND B.

Position of Disc	Binocular		Monocular	
	Behind A	In front of B	Behind A	In front of B
1	0 inches	20 inches	16 inches	21 inches
2	8 inches	8 inches	22 inches	15 inches
3	18 inches	1 inch	40 inches	-4 inches

The depth position of the disc was most correctly perceived with respect to a particular card when the smallest difference in visual direction occurred between the disc and that card. When the disc was in position 2, it appeared midway between the two cards in depth. This suggests that a simple relationship exists between the apparent depth position of the disc and the ratio of the lateral separations of the disc from each of the cards. The second hypothesis is illustrated by the monocular results of Table 1. As the disc was placed laterally farther from card A and laterally closer to card B, the average depth report increased with respect to card A and decreased with respect to card B. The position of least lateral separation of the disc from a card was the position at which the disc appeared nearest to that card in depth.

With monocular vision for 7 out of 12 subjects, the apparent depth between the disc and a particular card increased with each increase in the lateral separation of the disc from that card. The probability of this continuous increase in apparent depth occurring by chance

for a single subject is 1/4. Using a "p" of 1/4 and a "q" of 3/4 in the binomial expansion, the probability of 7 or more subjects out of 12 seeing this continuous increase is significant beyond the 2 per cent level of confidence. A similar analysis of the reports with binocular observation results in a statistical significance beyond the .1 per cent level of confidence.

Discussion

The situation to which these two hypotheses were applied is the apparent motion of a small object attached to the Ames rotating trapezoidal window. Ames (1) found that if a window which was made in the form of a trapezoid was rotated, it would appear to oscillate back and forth. He also found that a cube attached to an end of the rotating trapezoidal window would appear to leave its point of attachment and to move in a circular path. In discussing the movement of the cube, Ames remarks (1, p. 18):

> "In its rotation as the cube comes toward us, its retinal image increases, and we assume it is coming nearer to us; as it goes away from us, its retinal image becomes smaller, and we assume it is going away.... The variations in the sizes of the retinal images and the rate of their movement across our retina, although not uniform or constant in time, are nevertheless so translated, and the cube appears to be moving in a circular path at a relatively constant speed."

Kilpatrick (4) attached a playing card on the top of the small end of the rotating trapezoidal window. In one case, the card was in the plane of the window and in another case, the plane of the card was perpendicular to the plane of the window. Using monocular vision, the card appeared in the former case to oscillate with the window, while in the latter case, "the 'real' motion of the card was perceived" (4, p. 155). Kilpatrick attributes the difference in the apparent motion of the card in these two cases to observer assumptions of "togetherness" or "apartness" of the card and window.

Figure 2 contains schematic top-view drawings of a trapezoidal window. A thin (two-dimensional) square is rigidly attached to the large end of the window. A top-view drawing of the square would be a short straight line in, or parallel to, the long straight lines representing the window. In Figure 2 the square is drawn as a square in order to distinguish it from the window. Actually, the squares drawn in Figure 2 represent an object whose thickness is no greater than the thickness of the window. The letters L and S stand for the large and small end of the window, respectively. The physical positions of the trapezoidal window and the square are indicated by the solid straight lines and the filled-in squares, respectively. The apparent positions of the window and square for each physical position shown directly above it are indicated by the dashed lines and outline squares. The apparent positions of the window are either those shown by Ames (1, p. 6), or are interpolations between those shown by Ames. The left half of Figure 2 is concerned with binocular observation of the window and square, and the right half with monocular observation of the window and square. A top view of the eye or eyes of the observer should be imagined as being located below each drawing of Figure 2.

A two-dimensional object can be attached to the trapezoidal window so that its visual direction with respect to each part of the window changes as the window is rotated. A situation of this type is shown in the upper half of Figure 2. The square is rigidly attached to the large end of the window but is displaced from the plane of the window. Or, the two-dimensional object can be attached so that, throughout the rotation of the window, there is little difference between the visual direction of the object and that part of the window to which it is attached. A situation of this type is shown in the lower half of Figure 2. The square is rigidly attached at the large end of the window and is in the plane of the window.

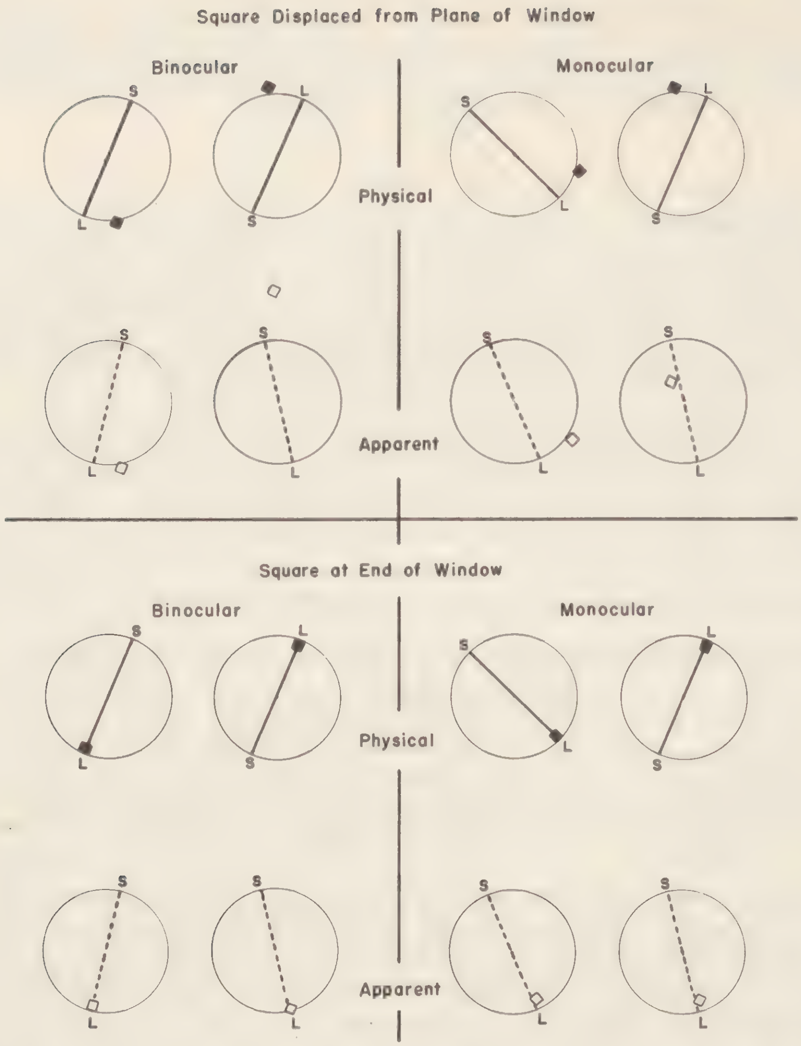

Figure 2. Physical Positions and Expected Apparent Depth Positions of a Square with Two Conditions of Attaching the Square to the Trapezoidal Window.

Consider the upper left quadrant of Figure 1. In the upper left drawing of this quadrant, the large end of the window is physically in front of the small end, and the square has approximately the same visual direction as the small end. The square is physically in front of the small end by approximately one length of the window. From the first hypothesis, the apparent position of the square will also be approximately one length of the window in front of the small end. But (as shown in the lower left drawing of this quadrant) the large end of the window appears closer to the observer than the small end. Consequently, the square should appear to be in the depth vicinity of the large end. In the upper right drawing of this upper left quadrant, the square has the same visual direction (line of sight) as the portion of the window which physically is approximately one-fourth of a window length behind the small end of the window. The square is physically a certain distance "d" behind this portion of the window. It should, by the first hypothesis, also appear to be distance "d" behind this portion of the window. But the small end of the window appears to be behind the large end (as shown in the lower right drawing of this quadrant). Therefore, the square by appearing to be a distance "d" behind the portion of the window with which it is in line of sight, should also appear to be behind the apparently far end of the window. This means that when the window rotates from the physical position shown by the upper left drawing of this quadrant to the physical position shown by the upper right drawing of this

quadrant, the apparent position of the square (as shown by the lower drawings of this quadrant) should move from the depth vicinity of the apparently near end of the window to a depth position in back of the apparently far end of the window.

Consider the lower left quadrant of Figure 2. The large end of the window is at the same visual direction as the square and would remain so throughout the rotation of the window. In this case, according to the first hypothesis, the physical depth position of the square should always be "correctly" perceived with respect to the large end of the window. The large end of the rotating trapezoidal window appears to oscillate back and forth and the square (as shown by the lower drawings of this quadrant) should appear to oscillate also.

The method of predicting the apparent depth position of the square for monocular observation from the physical and apparent position of the window and the physical position of the square is similar to that discussed for binocular observation. But the physical depth position of the square should not necessarily be correctly perceived in relation to the portion of the window which has the same visual direction. Instead, from the second hypothesis, the expected apparent depth position of the square would be near the depth position of this portion of the window. With monocular as with binocular observation, displacing the square from the plane of the window (see the upper right quadrant of Figure 2) should make the square appear to vary its depth position in relation to the rotating trapezoidal window. But the square in this position should not appear to move as far back in relation to the window with monocular as with binocular observation. In the lower right quadrant of Figure 2, the square with monocular observation is in the plane of the window at the large end. When the window is rotated, the square should appear to oscillate with the large end of the window (as indicated in the lower two drawings of this quadrant).

Experiment II

Apparatus

To test these predictions, a 3/4-inch white square was attached by a thin black wire to the large end of a trapezoidal window. This window was part of a kit (Portable Model Catalog No. RTW 1) obtained from the Institute for Associated Research, Hanover, N.H. The window was rotated in a counterclockwise direction, using four alternate positions of the square with respect to the window. These positions are illustrated in Figure 3 which shows the trapezoidal window with its plane at a right angle to the line of sight of the observer. In position A, the square was in the plane of the window one-half inch above the large end. In position B, the square was in the plane of the window three inches above the large end. In position C, the square was in the plane of the window but extended three inches beyond the large end. In position D, the square was displaced three inches from the plane of the window.

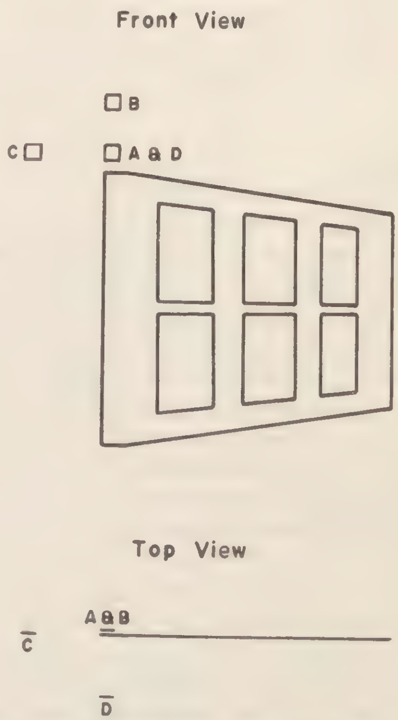

Figure 3. Physical Positions of the Square with Respect to the Window.

The rotating trapezoidal window was presented 10 feet from the subjects against a dark background, and was viewed through one or through two eyepieces. The eye or eyes of the subjects were at the height of the middle of the window. When the window and square were illuminated, they appeared to be in front of a uniform dark grey background.

Procedure

Twenty-four men were used as subjects. After some preliminary observations with 15 of these, it was decided to have the subjects indicate the apparent path of the square by drawing a simple top-view diagram of this path in relation to the center of the window. If the square appeared to move behind the large end of the window, the subjects were asked to specify the position at which the square appeared to pass through the plane of the window behind this apparently near end. Each subject was presented with the square at each of its four positions with monocular and with binocular observation of the window and square. The order of presenting the various situations was varied between subjects with respect to (a) whether the binocular or monocular view was presented first, and (b) the order of presenting the four positions of the square.

Expected Results

As suggested by Figure 2, for both monocular and binocular observation, the square in position A should appear to oscillate with the apparently near end of the window. In position D, the square should appear to move independently of the window through part of its travel, appearing to pass through the plane of the window behind the apparently near end. With position B, the large end of the rotating window always has a smaller difference in visual direction in relation to the square than has any other portion of the window. Therefore, position B with either monocular or binocular observation should give results similar to those from position A. With position C, also, the large end of the window is always the portion of the window closest in visual direction to the square. But the square is physically sometimes in front and sometimes behind the large end and should, therefore, show with binocular observation some independent movement in relation to this end. However, with binocular observation, the square in position C should appear to move less far back in relation to the window than the square in position D. Since the form of the relation involved in the second hypothesis is not specified, it is not clear with monocular observation whether the path of apparent movement of the square in position C would be expected to differ from that in position A or B. With position D, it is expected that the square will appear to move back farther in relation to the window when binocular rather than monocular observation is used.

Results

For 22 of the 24 men who were used as subjects, the window appeared to oscillate through all of its rotation with both monocular and binocular observation. With the remaining two men, the oscillation was momentarily disturbed at the maximum point of the illusion when binocular observation was used. Two men who reported with binocular observation that the apparent oscillation of the window was disturbed through an appreciable segment of the rotation were not used as subjects. The average results, in units of the window, at which the square appeared to pass through the plane of the window behind the apparently near end is given in Table 2 (see Figure 2 for illustrations of this phenomenon). For example, with both monocular and binocular observation, the square in position A appeared to oscillate back and forth with the end of the window to which it was attached. This is indicated by the average reports of 0 in Table 2. But in position D, with binocular observation, the square appeared to move independently of the window through part of its travel, appearing to pass over the window at an average distance of 83 per cent of the length of the window behind the apparently near end. It will be seen that the direction of the differences between the average results from the four positions of the square are in good agreement with the predicted changes. Also, as predicted, the average report for position D was larger with binocular than with monocular observation.

The t test was used to determine the significance of the predicted differences between the means of Table 2. The average report from binocular observation, with position D,

was significantly different from that with position A, B, or C beyond the .1 per cent level of confidence. Also, the average report from binocular observation with position C was significantly different from that with position A or B beyond the 5 per cent level of confidence. The average report from position D with monocular observation was significantly different from that from positions A, B, or C beyond the .1 per cent level of confidence. With either binocular or monocular observation, the average report from position B was not significantly different from that from position A at the 10 per cent level of confidence. The average report from position D with binocular observation was significantly different from that from position D with monocular observation at the .1 per cent level of confidence.

TABLE 2

PORTION OF THE ROTATING TRAPEZOIDAL WINDOW OVER WHICH THE SQUARE APPEARED TO PASS WITH THE CONDITIONS ILLUSTRATED BY FIG. 3.

	A	B	C	D
Binocular	0	.05	.22	.83
Monocular	0	.05	.17	.43

There are some indications that factors other than those represented by the two hypotheses were operating. The average report from position D for binocular observation was not as large as expected. From the first hypothesis, the square in position D should have appeared to move completely behind the window. Also, the average reported shape of the path of movement of the square in position D with monocular observation was different from the shape which was expected from the second hypothesis. The results of this experiment, however, demonstrate that many differences between the various conditions can be successfully predicted from the two hypotheses.

Ames has indicated that the apparent oscillation of the rotating trapezoidal window was disturbed with binocular observation when the distance of the observer from the window was about 10 feet (1, p. 9). In the present experiment, the subjects were asked to make a simple top-view drawing of the apparent motion of the window prior to being presented with the attached square in each of its four positions. Also, during the viewing of each of the four positions of the square, the subject was questioned about the apparent motion of the window. As discussed previously, with 22 subjects there was no reported disturbance in the apparent oscillation of the window for either binocular or monocular observation. This difference between the results of the two studies might be attributed to the presentation of a rectangular window above the trapezoidal window in the experiments of Ames. If, for example, the ends of the rectangular window were in the directional vicinity of the corresponding ends of the trapezoidal window, there should, from the first hypothesis, be some tendency to see the correct orientation of the windows in relation to each other.

These hypotheses also have implications for the demonstration in which a tube was placed through the rotating trapezoidal window (1) and for a demonstration by Kilpatrick and Ittleson (5) in which a moving card passed through the plane of a stationary trapezoidal window.

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SOME ASPECTS OF THE BASIS OF STEREOSCOPIC VISION

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The question whether simultaneity is a factor associated with disparity between the images in the two eyes, necessary for the emergence of the stereoscopic experience, will be discussed in this paper. Must the two stimuli be received by the two eyes at the same time and must they fall on specific horizontally associated retinal elements? There no longer is a question regarding "simultaneity" with respect to time, for it is well known that stereopsis can be obtained from disparate after-images which are induced in each eye separately (1). Experiments show however that stereoscopic depth from after-images is experienced only as long as the disparate retinal elements involved are in an excited state at the same time (2).

Simultaneity with respect to retinal location concerns the question whether the disparate stimuli, at least in part, must fall on specific horizontally associated disparate retinal elements. In 1873 van der Meulen and van Dooremaal (3) reported their observations that bear on this question. They used the Hering "falling sphere" test. In this test, through a horizontal slit-aperture, the subject views a vertical thread (plumb line) as fixation object, and judges whether a small sphere dropped by an assistant appears to fall in front of or behind the fixed plumb line. A prism was placed base down before one eye so that the image of the slit to that eye would be seen entirely above the actual slit seen by the other eye. The images of the plumb line would be uninfluenced and would appear just the same as before. A small sphere now dropped near the plumb line would not be seen simultaneously by the two eyes. The upper half of the path of the fall would be seen by one eye, the lower half of the path would be seen by the other eye.

It was reported that the path of the falling sphere nevertheless could always be correctly judged nearer or farther than the plumb line. These authors concluded that stereoscopic depth is not to be conceived as a direct physiological phenomenon, but as a psychical one, that is, the depth is produced by a psychophysical process. In this experiment the stereoscopic vision arises solely through the means of imagined prolongations of the half-images, which then in the usual stereoscopic manner would be referred to horizontally disparate retinal points.

As far as the writer can learn, this experiment has never been subjected to a critical analysis. But certainly evidence from experiments designed to test this spatial factor specifically should bear directly on the problem of whether stereoscopic vision rests upon a neuro-anatomical and physiological basis or whether it is fundamentally a psycho-physical phenomenon. The purpose of this paper is to report the results of experiments which, under controlled conditions and improved instrumentation, extend the basic experiment performed by van der Meulen and van Dooremaal.

Apparatus

The instrument used was a further modification of the haploscopic device previously described in the study of the precision and validity of stereoscopic depth (4). The subject, whose head was held accurately, fixated a brightly illuminated spot on a sheet of plate glass 50 cm. from the eyes. The subject also saw the images of a reference and a test object by reflection from suitable mirrors (50-50 transmission-reflectance). A highly polished thin, steel drill rod, mounted vertically, served as reference object and was seen by

reflection from a fixed mirror. A brilliant vertical line resulted when this rod was suitably illuminated.

The test object was either a drill rod identical to that used for the reference line, or was a falling sphere as in the Hering test. The test object was seen by reflection from the mirror combination nearest the eyes. These two mirrors, when rotated about vertical axes through small angles in directions opposite to each other, produced a change in the disparity between the images of the test object, and accordingly produced a change in the stereoscopic depth of the test object relative to the fixation point or to the reference line. This experimental arrangement virtually eliminated all empirical clues to spatial localization for the test object.

The mirror rotations were controlled by a hand wheel through suitable levers and a screw arrangement. A dial indicator showed the amount the mirrors had been turned and therefore the angular disparity between the images of the test line (minutes of arc). An estimated 1/5 scale division corresponded to 6 seconds of arc angular disparity.

The drill rods used as the test and the reference objects could be illuminated continuously, or momentarily by means of a time switch.

The falling-sphere attachment consisted of a suitable reservoir for holding the 1/16-inch spheres, and a mechanism for releasing these. A long cable release when pushed caused a sphere to fall into a cup below the field of vision of the subject.

The binocular visual field was restricted to the fixation point and to the images of the reference and test objects by suitable horizontal slit apertures and a septum. The fixation point and the images of the reference and the test objects were seen against a large evenly illuminated white background. The individual backgrounds for the reference and test objects were completely black. The principal aperture screen was illuminated to about the same brightness as that of the background. The experiment was otherwise conducted in a semi-darkened room.

A screening or baffle device consisting of two thin square pieces of blackened metal was interposed in front of the test object. The two baffle plates could be accurately adjusted for any given vertical separation or gap. Through this gap both eyes could see a central portion of the test line. The baffles were adjusted as necessary so that one eye saw the entire upper portion of the line but not the lower and the other eye saw the lower portion but not the upper. Thus each eye saw the same length half-image of the test line irrespective of the width of the gap through which both eyes could see the same central portion of the line.

The apparatus was first set up to use the drill rods, and therefore the reference and test objects consisted of bright lines. With the subject's head in the instrument the reference line was adjusted so that it would appear at the same distance as the fixation spot, but 1.5 arc degrees to the left of it. Thus the disparity of the images of the reference line, with respect to the fixation point, was substantially zero. The arm that supports the test line was then adjusted so that its images would be 1.5 arc degrees on the right of the fixation spot. As the operator or subject turned the handwheel controlling the rotation of the mirrors, thereby changing the angular disparity of the images of the test line, the test line appeared to move stereoscopically in front of or behind the plane of the fixation point and the reference line.

For this first set of data, the test and reference lines were illuminated for 0.2 second. This exposure was short enough to prevent any serious influence of eye movements and at the same time was long enough to assure an adequate stimulus for stereoscopic depth perception.

When the method of adjustment was used, the subject while carefully fixating the fixation spot adjusted the knob to a position chosen at random, exposed the lines, and judged whether the test line was seen farther or nearer than the reference line. The knob was adjusted again and another judgment was made. Thus a procedure of successive approximation was continued until the subject felt that the test line and reference line appeared at the same distance. The dial indicator reading was then recorded. From a series of observations the angular disparity corresponding to the average setting and to the standard deviation was computed. The stereoscopic sensitivity bears an inverse relation to the standard deviation.

Then the positions of the reference and test lines were interchanged, and the entire series of data was repeated. This interchange in position was necessary in order that the effects of a possible cyclotorsion of the eyes, asymmetric errors in retinal organization, and errors in the apparatus could be eliminated from the two sets of data. Data were obtained in a series of steps of decreased vertical gap, until finally stereoscopic depth could no longer be experienced.

Results

The standard deviations of the settings are plotted as ordinates, and the angular length of the binocularly seen parts of the half-images (the gap) is plotted on the abscissa. Inspection of a typical graph shows a regular but small increase in the standard deviation as the binocular portions of the half-images were decreased. When the binocularly seen portion was reduced to zero or even when the baffles were adjusted so that there was an actual vertical separation between the half-images of the test line, the standard deviations increase markedly and are less consistent. Furthermore, in this negative gap range, no stereoscopic depth was experienced for a large proportion of the times that the lines were exposed, and the observations were often uncertain and judgments difficult to make. The data do show that the stereoscopic sensitivity is markedly decreased, or almost absent, when the gap has been reduced to zero.

However there was some subjective impression of depth even when there was a small but actual vertical separation between the two half-images. This result would be in agreement with those reported by van der Meulen and van Dooremaal, but the stereoscopic experience was certainly much more vague than that suggested by these authors. Indeed the data themselves show a precision of an entirely different order than when some portion of the test object was seen binocularly. But even this vague sense of depth ceased when the half-images were separated very far.

Now we might also anticipate that, in analogy with the vertical extent of Panum's areas of fusion, there could also be a vertical extent in areas for stereoscopic vision. That is, disparate images could also be vertically disparate, within certain limits, and still their horizontal disparity would be experienced in stereoscopic depth. The existence of such areas was suggested by the experimental work on the induced effect (5). The fact that depth was experienced even after the half-images were slightly separated might be explained on this basis. The inner ends of the two half-images might be said to fall within the vertical extent of these areas. The standard deviations become very large when the average separation between the half-images is about 16 minutes of arc. This might be interpreted to represent then the vertical extent of such areas. But this figure seems far too large. We would accordingly conclude that in the range of small horizontal disparities, near the central parts of the visual field, and for short exposure times, in addition to the existence of such a retinal area of stereoscopic vision, there appears to be some type of depth perception from separated half-images. This result is in accordance with the experiment of van der Meulen and van Dooremaal. However, these authors do not report any limits in this depth experience.

When the observations were made while the reference and test lines were continuously illuminated and therefore continuously visible, this apparent depth from the separated half-images could rarely be experienced or when the binocular portion of the test line was eliminated, it became extremely variable and subjectively uncertain. With this continuous visibility the stereoscopic sense of depth soon faded, and as the angle of disparity was increased the depth became even less evident.

When the falling sphere was used to replace the test line, however, the experience of depth was more definite with somewhat larger actual separations between the half-images of the fall. But although the apparent depth before or behind the fixation plane was perceivable with the separated half-images, it was not experienced every time the sphere fell. Thus it appears that with the falling sphere, a conception of depth based upon disparity of separated images is possible for larger vertical separations of the half-images, but at the same time there is some indefiniteness regarding the depth.

Now the possibility existed that the depth experience from vertically separated half-images would not be a quantitative experience of depth. The type of depth perceived with slightly vertically separated half-images might occur only with relatively small horizontal disparities of the images or for objects in the neighborhood of the fronto-parallel plane. Accordingly the reference line was placed in front of (or behind) the fixation point. Then the test object was adjusted so that it appeared at the same depth as the reference line, while fixation was maintained on the original fixation spot. The images of both the reference and test lines would be observed in equal crossed (or uncrossed) disparity. The exposure time of both reference and test lines was again 0.2 second.

The standard deviations as a measure of the stereoscopic threshold now suddenly increased when the length of the portions of the disparate half-images seen simultaneously binocularly approached zero. Thus stereoscopic depth virtually ceased when no portions of the horizontally disparate half-images could be seen binocularly.

When also plotted against gap size, the average disparity corresponding to the mean settings of the sets of data was fairly constant until the vertical gap between the baffles approached zero. Then the mean disparity for one subject corresponding to apparent equal depth suddenly decreased. This is to say that the depth of the test line as referred to that of the reference line was unchanged by a decrease in the length of the binocularly seen part of the test line, until that length became small. Then the disparity between the half-images corresponding to the same apparent depth of test and reference lines decreased. This change in the mean disparity was fairly consistent for most of the data taken by the one observer, although occasionally in a given set of data it did not occur. For the other observer, however, the break was more likely to be in the opposite direction; that is, the disparities of the images of the test line had to be increased for the test images to appear the same distance as the reference line. That empirical factors are involved is suggested, because when the brightness of the reference and test lines are made very unequal, the direction of the change in disparity for the mean settings could be altered. This break in the course of the mean disparities may be more important than the change in standard deviations in showing the breakdown of a quantitative stereopsis when simultaneous binocular perception is prevented.

When the falling sphere replaced the line, and then the binocularly seen portion of the fall was decreased by closing the gap between the baffles, it became increasingly difficult to make the adjustments that would cause the falling bead to appear as near in front of the fixation point as was the reference line. Again in many falls no judgment could be made at all —there was no specific depth perception. And yet the subject usually felt that he could judge whether or not the falling sphere was in front of the fixation point itself.

The data, obtained by two subjects in the experiments just described, clearly suggest that there may be two components in stereoscopic depth perception: a quantitative patent depth and a qualitative concept of depth, both however based upon disparity between the images. These two types are probably the same as the "patent" stereopsis and "qualitative" conception of depth already encountered in the experiments previously described on the disparity limits of stereoscopic vision (6).

As the terms quantitative or patent stereopsis imply, such depth perception is precise and subjectively certain. Subjective depth is related quantitatively to the disparity between the images in the two eyes. This type of stereopsis requires that there be simultaneous binocular perception, in the sense that horizontally associated disparate retinal elements of both eyes must be stimulated at the same time. This fact suggests that the basis of stereoscopic depth perception must first be physiological and be related to the neuro-anatomical organization of the two retinas with the cortex.

The qualitative concept of depth which exists especially for small disparities between the images need not be simultaneously perceived on horizontally associated disparate retinal elements in the two eyes. This association may be a comparison of distances of the half-images from the images of the fixation point. It is a somewhat vague experience of depth and seems to be related to objects near the objective fronto-parallel plane and the point of fixation. The depth is much more uncertain when the images are continuously seen, without eye movements. Short exposure of details enhances this depth experience. In ordinary surroundings fixating eye movements from one object to another would accordingly enhance this qualitative conception of depth. An increased number of objects in the field of view with the accompanying increase in binocular parallax clues would also enhance this qualitative type of depth response. We would be led to believe that the qualitative depth perception is empirical and results from experience in the life of the individual with such parallax clues or motives (Tiefenmotive).

The results of the experiment of van der Meulen and van Dooremaal would probably be explained on the basis of this qualitative depth sense. That the conclusions of these authors pertain to all of stereoscopic depth perception must be rejected.

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Discussion:

Dr. Fry inquired as to Dr. Ogle's thinking with respect to possible relations between fusional movements and stereopsis. Dr. Fry commented that fusional movements which produce error in the measurement of phoria, may be related to stereopsis.

Dr. Ogle stated that he was particularly interested in the relations between fusional movements and stereopsis. Dr. Ogle commented that his research efforts have been directed in part toward testing the view, now popular in Germany, that stereopsis arises from stimuli for fusional movements which cannot take place because of fusion.

Dr. Fry called Dr. Ogle's attention to the Zöllner illusion in which a stereoscopic impression results from binocular disparity produced by induction of the image in one eye. The existence of this illusion is taken by Gestalt psychologists as support for the motion that stereopsis consists of psychological interpretation of independently elaborated monocular impressions.

Dr. Ogle noted that his formal paper included references to the Zöllner illusion, but that he had personally been unable to elicit the Zöllner illusion. Dr. Ogle commented that, in his opinion, all the evidence attempting to demonstrate that stereopsis may be obtained from memory images was unconvincing and that the same was true for the notion that stereopsis can be obtained by presenting disparate images to one eye alone. Similarly, the evidence is not convincing that stereopsis can be obtained by combining images, one of which has been modified by induction.

Dr. Fry stated that he also had been unable to obtain stereopsis by means of the Zöllner illusion.

Dr. Ogle emphasized one aspect of his work, namely, that continuously exposed images do not give as strong a depth impression as images exposed momentarily or images, like the falling bead, which move. Dr. Ogle pointed out that in ordinary use of the eyes, images producing depth impressions are presented only momentarily because of the rapid movement of the eyes from fixation to fixation.

CDR Farnsworth commented on the fact that perceptual impressions seem to be so much reinforced when attention is not directed toward a particular phenomenon. This reinforcement is apparent in depth impressions. A parallel exists in the case of after-image. It is very difficult to obtain good after-images concentrating one's attention; a certain type of relaxation is necessary for the development of good after-images.

COMPARISON OF DIFFERENT TESTS OF BINOCULAR DEPTH PERCEPTION*

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Several previous investigators (1) have used the statistical techniques of correlation, and, in some cases factor analysis, to study the relationship between the scores on different tests of binocular depth perception. Poor agreement has generally been found, especially when subjects with subnormal acuities were excluded.

In the present study three representative tests were investigated from a physiological rather than from a statistical point of view in order to learn something about the reasons for this lack of agreement. The tests used were the Howard-Dolman, the Verhoeff Stereopter and the depth test of the Armed Forces Vision Tester made by Bausch & Lomb. In all three tests, cues associated with binocular retinal disparity are of primary importance. There are nevertheless significant differences in the experimental conditions under which depth perception is measured by each one. The results of our studies can best be understood if the more important of these differences are first discussed.

1. Presence or Absence of Auxiliary Uniocular Cues

One factor which we believe may have a bearing on the results of tests of binocular depth perception is the presence or absence of auxiliary uniocular cues. In the Howard-Dolman test, variation in the distance of the movable rod is associated with regular changes in the size of the retinal image. There are also changes in accommodation but these are extremely small at distances in the neighborhood of 6 meters. It was shown by Deyo (2) that the monocular threshold on the Howard-Dolman test is, for the average normal subject, about six times as great as the binocular threshold. Until recently, findings of this sort have generally been interpreted to mean that, in binocular vision, the retinal disparity cue is the sole determiner of the depth threshold. A somewhat different point of view has been presented in a recent study by Holway and his colleagues (3), who believe that the sensitivities to the cues of retinal disparity, size and accommodation are additive, and that even when the thresholds of the uniocular cues are much higher, they may nevertheless supplement the binocular disparity cue. The results of Holway's study are available only in photostat form and are not widely known. I am therefore presenting some of their findings which have a bearing on the results of our own studies. Figure 1 is based on tabular data taken from Holway's paper. D, the distance of the fixed test target is shown on the abscissa; S, the mean variation in the equality settings of the movable test target, on the ordinate. Both are plotted in logarithmic units. The data indicated by dots show the thresholds for monocular vision in which only size and accommodation cues were available. Those indicated by circles are for binocular vision in which disparity cues were present in addition to the uniocular cues. At a distance of 600 cm. (log D, 2.78) the monocular threshold is about 0.65 log units above the binocular; in arithmetic units about 4.5 times as great.

The data indicated by crosses in Figure 1 show the values of the binocular thresholds when retinal disparity was the only cue. In these experiments targets of the same dimensions as before were presented in a mirror haploscope. It is apparent from the graph that the binocular thresholds were significantly higher when the disparity cue was not supplemented

*This study was carried out under Contract NONR-248 (24) between the Johns Hopkins University and the Office of Naval Research.

by any uniocular cues. At a distance of 600 cm. for example, the threshold was about twice as great when no changes in size or in accommodation were associated with the change in retinal disparity. The findings of this study suggest that, in the standard Howard-Dolman test, the sensitivity to differences in distance may be increased by the changes in

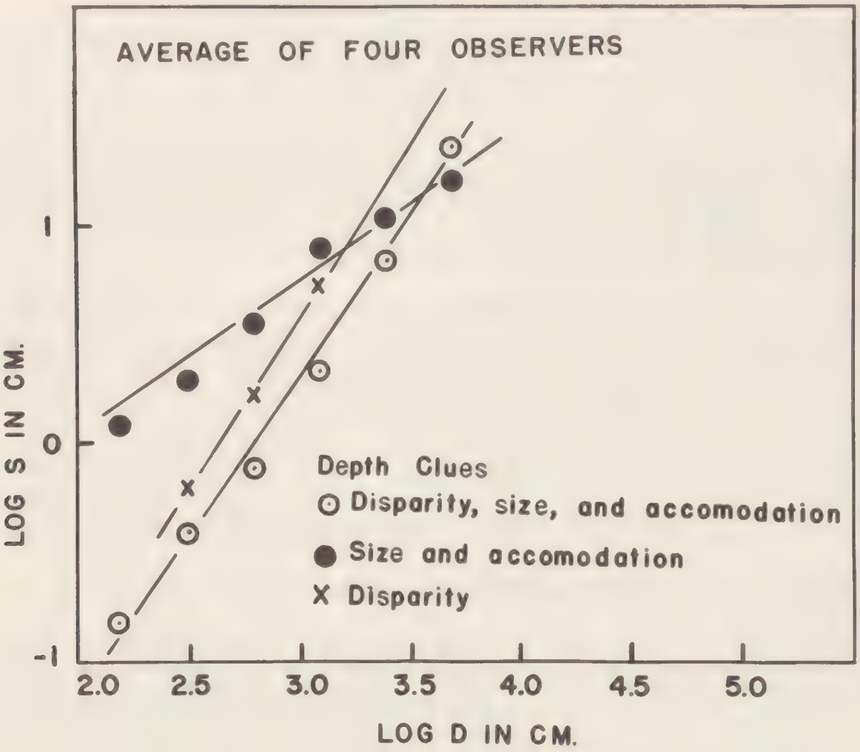

Figure 1

subtense which accompany changes in distance. Since a decrease in distance from 6 to 5 meters requires an increase in accommodation of only .003 diopters, we do not agree with Holway that the accommodation cue is also of importance. In the standard Verhoeff Stereopter the test targets are three vertical bars differing in width (i.e., 2, 2.5 and 3 mm.). These are presented in such a way that the size cues are always opposed to the cues from disparity and accommodation. However, since the rods differ in size by ±20%, rods of equal diameter would have to be located at widely different distances in order to produce the same differences in subtense. It is therefore difficult to predict just what effects, if any, result from the false size cues of this particular test. Our experimental findings, to be presented later, show that sensitivity to differences in depth may be slightly reduced by the conflicting uniocular and binocular cues. This was found to be true for some but not for all subjects. In the Vision Tester the apparent depth depends solely upon retinal disparity. The largest angular difference in depth, namely 40 seconds, corresponds to that of test objects at distances of 800 and 781 cm. If targets of equal size were <u>actually</u> located at these two distances the retinal image of the nearer target would be larger by about 2%. Previous studies (4) have shown that a difference of 2% in visual angle can be perceived under favorable circumstances. It is possible therefore that in the Vision Tester the absence of any change in visual angle might introduce a conflicting cue interfering with the perception of the difference in depth simulated by binocular disparity.

2. Distance of Test Targets

The distance of the test targets from the subject is a second factor which may have an important influence on the findings. In our studies, the Howard-Dolman test was given

at the usual distance of 6 meters. The targets of the Vision Tester are at an optical distance of 8 meters. In the Stereopter the testing distance must be varied in order to measure the threshold parallactic angle. The greatest distance at which correct judgments can be made ranges from about 1 to 2 meters for most normal subjects. Presbyopes are therefore at a disadvantage when the testing distance falls in the intermediate range beyond the limits of clear vision of their near glasses, and inside the limits of their distance glasses. Subjects with uncorrected myopias, on the other hand, may be expected to make relatively higher scores on the Stereopter than on tests given at 6 meters or more.

It has generally been assumed that the binocular depth threshold, when expressed in angular units of retinal disparity, is independent of distance. This assumption implies that the linear threshold is proportional to the square of the distance. The data of several previous studies show however that the threshold in angular units decreases with increase in distance. Hirsch & Weymouth's data (5), for example can be fitted to an equation which indicates that the linear threshold is proportional, not to D^2, but more nearly to $D^{1.6}$ Holway's experiments show a similar effect of distance. In Figure 1, for example, the straight line through the circles has a slope of about 1.5, showing that the linear threshold is proportional to $D^{1.5}$ instead of to D^2. A further evidence of the effect of distance is the higher angular thresholds found on the Stereopter than on tests given at greater distances. This will be discussed later in more detail.

EXPERIMENTAL STUDIES

1. Influence of False Size Cues on Stereopter Scores

The purpose of our first experiment was to investigate the possible influence of the false size cues of the Stereopter. Sixty-eight subjects were tested on the standard device and on a modified instrument in which rods 2 mm. in diameter were substituted for the rods of unequal width.

Table 1 shows the relationship between the thresholds determined with and without false size cues. The correlation between the two sets of scores is 0.90. The data suggest that the thresholds tend to be slightly greater with unequal than with equal rods. This is better shown in Figure 2 which gives for 61 subjects the distribution of the differences in the thresholds. [The data for seven whose thresholds were greater than 90 seconds in one or both tests are not included. For these subjects the differences might be spuriously large because tests were not made at intermediate distances between 90 and 132 seconds (60.5 and 50 cm.)]. For 48 of the 61 subjects, the thresholds determined by the two methods agreed within ±10 seconds. For the other 13, the thresholds were from 15 to 45 seconds greater when false size cues were present.

There are several possible interpretations of these findings. According to Verhoeff, the small group of subjects who are influenced by the false size cues should be considered as having inferior depth perception, because, he says, only the disparity cues can be relied upon always to give correct information. There is, on the other hand, evidence suggesting that, in the ordinary use of the eyes, auxiliary uniocular cues supplement and increase the efficiency of binocular depth perception (3, 6), and that sensitivity to uniocular as well as to binocular cues is therefore a desirable condition. From this point of view, tests in which the two types of cue are in opposition may give misleading information. It is possible therefore that elimination of the opposing size cues of the Verhoeff test might give a more valid measure of binocular depth perception.

Table 1

RELATIONSHIP BETWEEN SCORES ON STANDARD AND ON MODIFIED STEREOPTER

Modified		Standard														
Cm.	Seconds	10	15	20	25	30	35	40	45	50	60	70	80	90	132	
50.0	132													1	2	3
60.5	90														2	2
64.1	80											1			2	3
68.5	70										1		1	2		4
74.2	60										1			1		2
81.0	50															0
86.0	45								2	1	1	1				5
91.0	40					1					1	1				3
97.0	35						2	2	1				1			6
105.0	30				1	1	2			1						5
115.0	25			2	3	2	2	1								10
128.0	20		2	2	3	2	1	2								12
148.0	15		4	1	2											7
181.0	10	4	2													6
		4	8	5	9	6	7	5	3	2	4	3	2	4	6	68

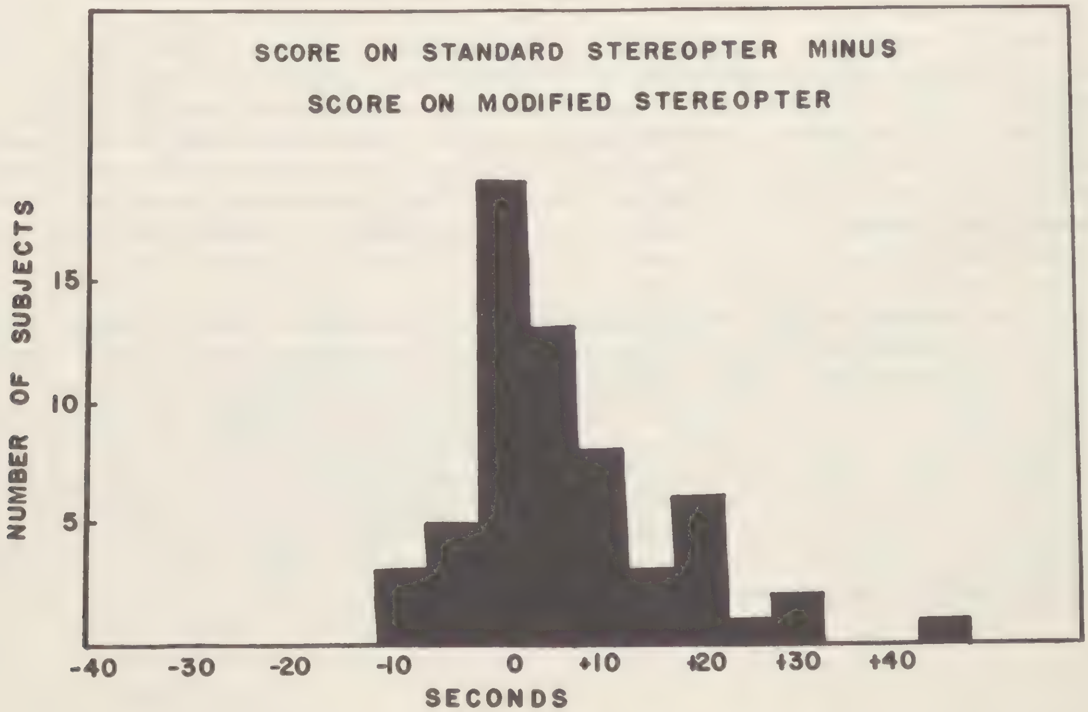

Figure 2

2. Comparison of Scores on Different Tests

In the second group of experiments of this study, 43 subjects were examined on two or more different tests in order to investigate the extent of agreement in the scores. All had visual acuities of at least 20/40 in each eye.

a. Howard-Dolman and Modified Stereopter

Table 2 shows the relationship between the MV scores in mm. on the Howard-Dolman test and the threshold parallactic angles in seconds measured on the Modified Stereopter in which the three rods were equal in width. Twenty-seven of the twenty-eight subjects with MV scores of 30 mm. or less on the Howard-Dolman had thresholds of 45 seconds or better on the Stereopter. (An angular disparity of 45 sec. corresponds to a testing distance of 86 cm.) Of the nine with MV scores greater than 30 mm. on the former test, seven had thresholds greater than 45 seconds on the latter. The one subject who made a score of 25 mm. on the Howard-Dolman test, but failed the Stereopter at 50 cm. (i.e., threshold greater than 132 sec.) made a zero score on the Vision Tester and on the preliminary fusion test showed evidence of intermittent suppression. Short intervals in which binocular vision was lost would be expected to result in failure on the Stereopter and Vision Tester, but would not necessarily result in a high mean variation score on the Howard-Dolman test. One subject with a poor Howard-Dolman score and a good Stereopter score had a low uncorrected myopia. In the third case of obvious lack of agreement in the scores on the two tests, no explanation for the discrepancy was found. With three exceptions among the thirty-seven subjects, therefore, these two tests agree in their classification of subjects as having good or poor depth perception. Within each group however there is an obviously low correlation in scores on the two tests.

Table 2

RELATIONSHIP BETWEEN SCORES ON HOWARD-DOLMAN TEST AND ON MODIFIED STEREOPTER

Verhoeff, parallactic angle in seconds	Howard-Dolman mean variation in mm.										
	10 or less	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51 or greater	
15 or less	3	1	1	1							6
20-25	5	2	2								9
30-35		5	0	1						1	7
40-45	1	1	2	1	1			1			7
50-55											
60-65											
70-75						1					1
80-85									1		1
90 or greater				1			1	1	2	1	6
	9	9	5	4	1	1	1	2	3	2	37

In order to compare the absolute values of the thresholds in units of parallactic angle, the millimeter scores of the Howard-Dolman test must be divided by 2.7. When this conversion is made it is apparent that much smaller values of parallactic angle can be discriminated on the Howard-Dolman test than on the Stereopter. A score of 30 mm. on the former, for example, corresponds to an angular disparity of 11 seconds, whereas the equivalent passing score on the Stereopter is about 45 seconds. This difference in the

minimum perceptible angular disparities, as measured by the two tests, is probably accounted for primarily by the distance factor previously discussed. If we assume in accordance with Holway's findings that S, the linear threshold, is proportional to $D^{1.5}$ rather than to D^2, then a variation of S from 10 to 30 mm. when D is kept constant at 6 meters (as in the Howard-Dolman test) should correspond to a variation in D from 204 to 98 cm. when S is kept constant at 2.5 mm. (as in the Stereopter). This prediction of the equivalent ranges of score on the two tests is not very different from that actually observed in the twenty-seven subjects with good depth perception on both tests.

b. Howard-Dolman and Standard Stereopter

Table 3 shows the relationship between scores on the Standard Stereopter and Howard-Dolman tests. Here too a passing score of 45 seconds gives the best agreement with a passing score of 30 mm. By these criteria four subjects pass the Howard-Dolman test but fail the Stereopter. One of these is the subject with intermittent suppression mentioned previously. The failure of the other three is perhaps explained by an especial sensitivity to the false size cues, since when tested with rods of equal width they made passing scores.

Table 3

RELATIONSHIP BETWEEN DEPTH SCORES ON HOWARD-DOLMAN TEST AND ON STANDARD STEREOPTER

Verhoeff, parallactic angle in seconds	Howard-Dolman, mean variation in mm. 5-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51 or greater	
15 or less	2			1							3
20-25	6	3	1	1							11
30-35		3	3								6
40-45		2	2								4
50-55								1		1	2
60-65	1				1	1					3
70-75				1							1
80-85											
90 or greater				1					1	1	3
	9	8	6	4	1	1		1	1	2	33

c. Howard-Dolman Test and Vision Tester

Table 4 shows the relationship between the MV scores on the Howard-Dolman and the letter scores of the Vision Tester. Twenty-four subjects have MV scores of 30 mm. or less associated with Vision Tester scores of D or better; ten have MV scores greater than 30 mm. associated with Vision Tester scores of B or poorer. The one subject with a score of F on the Vision Tester and a very poor Howard-Dolman score, when retested two months later made a score of 11 mm. This suggests lack of effort on the first Howard-Dolman test. Eight subjects making MV scores of 30 mm. or better on the Howard-Dolman test, were nevertheless unable to perceive the depth differences of the easiest items of the Vision Test. Four of these were given additional practice, both on the Vision Tester itself and on other stereoscopic devices. When retested after this training, three made the maximum score of F and one showed no improvement.

Table 4

RELATIONSHIP BETWEEN SCORES ON HOWARD-DOLMAN TEST AND ON VISION TESTER

Depth Test of Vision Tester		Howard-Dolman, mean variation in mm.										
Instrument score	Parallactic angle in seconds	5-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51 or greater	
F	15-17	5	6	1	2						1	15
E	21-21.5	1	1	1								3
D	25-28	2	1	2	2							7
C	30-32											0
B	39-41								1			1
O*			2	3	1	2	1	1	1	4	2	17
		8	10	7	5	2	1	1	2	4	3	43

*A score of 0 indicates that test item B was failed in two successive trials.

d. Factors Responsible for Consistently Poor Performance on All of the Tests of Depth Perception

In the group of forty-three subjects there were eleven who showed consistently poor depth perception on every test that was given. On the preliminary fusion test of the Vision Tester two of these showed an intermittent and two a constant suppression of the retinal image of one eye. A lateral tropia was revealed by this test in two other cases. According to the standard procedure for administration of the Vision Tester, failure on the depth test would be assumed, and the test therefore omitted, when obvious deficiencies in binocular vision are revealed by the fusion test. The other five subjects who failed all of the tests showed no evidence of either suppression or tropia on the fusion test. Two were later examined in the Orthoptic Clinic of the Wilmer Institute and found to have intermittent tropias at distance. Two others, who wore glasses during the depth tests, had high anisometropic errors of refraction. One of these was tested on the Space Eikonometer, and found to have an anisokonia requiring a correction of 3% axis 180°, right eye; 1% axis 90°, left eye. In the fifth case the only explanation found for the poor depth perception was the fact that the patient was tested while wearing newly acquired glasses. He made a score of 50 cm. (132 seconds) on the Stereopter, and a score of 49 mm. on the Howard-Dolman test. On retests after the glasses had been worn for three weeks the Stereopter threshold was 91 cm. (40 seconds) and the Howard-Dolman score was 16 mm. In these eleven subjects, consistently poor depth perception appears to have been associated primarily with obstacles to binocular fusion. Seven of the eleven had visual acuities of 20/20 or better in each eye. In four cases the visual acuities of 20/30 to 20/40 in the poorer eye may have contributed to the poor depth perception. Since phoria tests were not routinely given to this group, the possible relationship between heterophoria and depth perception cannot be evaluated. An additional group of 109 subjects was therefore examined on the Vision Tester to obtain systematic information as to the effects of subnormal acuity and heterophoria on binocular depth perception.

3. Relationship of Acuity and Phoria Scores to Depth Scores on Vision Tester

The 109 subjects were medical students, instructors, secretaries, technicians, clerks and a few domestic employees of Johns Hopkins Hospital who volunteered to take the visual

tests while awaiting examination in the Personnel Health Clinic. The following distance tests were given on the Vision Tester: acuity of each eye, vertical and lateral phorias, fusion and depth perception. About half of those scoring less than E on the Depth Test were given one or more additional trials, either in the same session or on a later date, to see whether their scores improved. Table 5 shows the test and retest scores of the twenty-nine subjects given such additional tests. It is apparent that there is a considerable learning factor, since seventeen of the twenty-nine make higher scores on repetition of the test. The findings suggest that, even though preliminary practice items are provided, poor scores may nevertheless result from lack of familiarity with devices in which the uniocular cues are not in accord with the binocular cue based on retinal disparity.

Table 5

RELATIONSHIP OF TEST AND RETEST DEPTH SCORES
ON VISION TEST

First Test

Retest	O	B	C	D	
O	5	5			10
B	3	1			4
C	1	0	1		2
D		2	3		5
E		2	2	1	5
F			1	2	3
	9	10	7	3	29

The relationship between the acuity of the poorer eye and the depth score is shown in Table 6. Although there was no selection on the basis of visual acuity, only two subjects had acuities less than 20/40. The data indicate that poor depth scores occur more frequently in those with acuities less than 20/20 in one or both eyes. Table 6 shows that when the depth scores are based on a single test, about 72% of those with good acuity have scores of D or better, as contrasted with 46% of those with less than 20/20 in one or both eyes. In the second part of the table the subjects are classified in accordance with the retest depth scores when more than one test was given. In this case the percentages making scores of D or better are 85% in the group with acuities of 20/20 or better, 50% in the group with acuities less than 20/20. The fact that relatively good depth scores are made by many with acuities ranging from 20/25 to 20/40 is not unexpected, since the effect of blurred imagery on binocular depth perception varies with the type of uncorrected refractive error. Blurring of the retinal image limited to the vertical meridian (astigmatism at axis 180°) reduces acuity but has little effect on the perception of differences in depth based on horizontal retinal disparities. A further analysis of the data was made to investigate the relationship between the depth perception scores and the amounts of vertical and lateral phoria. Only seven of the 109 subjects had significant amounts of hyperphoria ranging from 1-2 prism diopters. Three of these had depth scores of D or better, and four had scores of C or poorer. Because of the small number of cases, and the low degrees of hyperphoria, no conclusions can be drawn as to the possible effects of hyperphoria on depth perception.

Table 7 shows the relationship between the lateral phoria and the depth scores. Of the 109 subjects, 99 had only small amounts of lateral phoria ranging from 4 prism diopters of exophoria to 5 prism diopters of esophoria. Of the ten subjects with lateral phorias outside these limits, nine had depth scores of C or poorer.

Table 6

RELATIONSHIP BETWEEN ACUITY AND DEPTH SCORES ON VISION TESTER

	TEST		RETEST (when given)		
	D or better	C or poorer	D or better	C or poorer	
20/20 or better	47	18	55	10	65
20/25 or poorer	20	24	22	22	44
	67	42	77	32	109

It appears from our studies that poor binocular depth perception can generally be attributed to one or more of the following causes: tropia, suppression, subnormal acuity and high phoria. On the particular tests investigated in this study low scores can also occur in the absence of any of the above factors. On the Howard-Dolman test, for example, lack of skill or effort in making the required eye-hand coordinations may occasionally result in a falsely low score. On the Standard Stereopter, the conflict between size and disparity cues may reduce the score, and result in what we could classify as a "false failure." The frequent occurrence of this type of failure on the Vision Tester is probably also explained by the conflicting evidence from uniocular and binocular cues. There was no evidence in these studies suggesting that falsely poor scores might occur on the modified Stereopter except perhaps in presbyopes. On the other hand, both Stereopter tests can lead to a false indication of good depth perception at distance in the case of subjects with uncorrected myopia. The Howard-Dolman test may occasionally fail to detect the poor depth perception caused by intermittent loss of binocular vision. None of our results indicated that falsely high scores could occur on the Vision Tester.

Table 7

RELATION OF LATERAL PHORIA SCORES TO DEPTH SCORES ON VISION

	First Test		Retest (when given)		
	D or better	C or poorer	D or better	C or poorer	
Low Phoria (4 exo to 5 eso)	66	33	76	23	99
High Phoria (more than 4 exo or 5 eso)	1[a]	9[b]	1[a]	9[b]	10
	67	42	77	32	109

a. Esophoria of 11^{Δ} or more.

b. Eight of these had esophoria scores of $6\text{-}8^{\Delta}$.
One, having an exophoria score of 7^{Δ}, was shown by the fusion test to have an exotropia.

Our data suggest that if the visual requirements for specific tasks demand not only good depth perception but also high acuity, good binocular fusion, and low phoria, then many of those with really poor depth perception will automatically be disqualified by the tests for the other visual functions. Let us suppose, for example, that the qualifying visual standards require (a) visual acuities of 20/20 or better, (b) absence of tropia or suppression, (c) vertical phorias at distance less than 1 prism diopter, and (d) lateral phorias at

distance less than 4 prism diopters of exophoria or 5 prism diopters of esophoria. In our series of 109 subjects there were fifty-six who met the above criteria and who moreover were given additional practice and retested on the depth test unless they made a score of D or better on the first test. Table 8 shows the distribution of the depth scores of these subjects. On the first test eleven made scores of C or poorer; on the retest, only three. If therefore no depth tests had been given, the group of fifty-six subjects meeting the other visual criteria would include three, or about 5%, whose depth perception was subnormal on repeated tests. If on the other hand, only one depth test had been given, and a passing score of D or better were required, then not only these three would be disqualified, but also eight others who on the basis of the retest scores may actually have good depth perception.

Table 8

DISTRIBUTION OF DEPTH SCORES (VISION TESTER) OR SUBJECTS MEETING CERTAIN STANDARDS OF ACUITY, FUSION AND PHORIA (SEE TEXT)

Depth Score	Distribution of Cases According to First Test	Retest*
O	0	3
B	7	0
C	4	0
D	8	9
E	8	12
F	29	32
Total	56	56

*All subjects with scores of C or poorer were retested.

Whether or not it is advisable to include a test of depth perception when high standards of acuity, fusion and muscle balance must also be met depends upon the relative importance of eliminating unsuitable subjects and of not disqualifying suitable ones. In order to have high efficiency in both aspects of selection, a better test of depth perception is needed than that of the Vision Tester in its present form.

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STUDIES ON BATTLEFIELD ILLUMINATION

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I. GENERAL DESCRIPTION; PSYCHOPHYSICAL STUDIES

For some period of time it has been quite apparent that the night time use of scattered light provides significant visual advantages to troops advancing from the direction of the source under battlefield conditions. Practical experience in the battlefield has additionally shown that such light introduces certain disadvantages for troops advancing in the direction of the source. These factors have been discussed by Mr. Noffzinger of Fort Belvoir at an earlier meeting of this Committee and by Captain Orr of Fort Belvoir at later meetings of related groups.

It was the original purpose of the project to be described to attempt to define the kinds of advantages and disadvantages manifest in the use of scattered light of searchlight origin and to measure as critically as possible those limitations which would apply to the use of this light in tactical night battlefield problems. It was our feeling that a determination should be made of what the human subject required in the way of illumination in the visual detection problem and that the problem of presenting the required illumination, while no less important, might logically be investigated latterly. The problem of light distribution from the searchlight became paramount, however; thus, we have constructed a number of isofootcandle curves which will be discussed in full in the following paper.

Our early intentions regarding the psychophysical aspects of the problem were to proceed with the necessary measurements in a laboratory framework within which the innumerable variables of the field situation could have been more consistently controlled. This would have involved detection by subjects of three-dimensional targets under conditions approaching scatter light illumination from a source approximating the general purpose searchlight with simulation of distance effects. However, existing effective opinion decreed that the project be organized as a field operation. Immediately certain limitations were imposed upon the type of data we were able to collect. Thus, movement on the part of the target or the subject was ruled out since this type of variable would have complicated our measurements beyond relief. The targets would have to be few in variety and simple in presentation since target variations and target mobility would introduce undesirable mechanical and observer complications. For reasons of ease of mobility, simplicity of selection and replacement, and facility of procurement, we chose a human target. Additional simplicity decreed "detection" rather than recognition or identification as the threshold criterion. Further problems were introduced and have qualified our results for the field operation. Thus, the density and quality of the contrast background vary with the season, inability to match standard lamp and searchlight spectral characteristics have introduced certain calibration difficulties, the availability of moonless nights for only one-third of the month (and these not always free of mist or rain) introduced scheduling difficulties. Mechanical and electrical failures and deficiencies in the isolated field further cut our efficiency and not the least important were long night hours after full days of work that together with mosquitoes, mud and excesses of heat or cold, took their inevitable large toll of motivation and, consequently, consistency and validity of threshold measurements of the subjects as well as illumination measurements in the field.

The site chosen for the experimental range was the Bonnet Carre Spillway which will be referred to as the "spillway" hereafter. This is a rectangular section of low-lying

land about 20 miles north of New Orleans and bounded on the west by the Mississippi River, flood waters from which are diverted to Lake Ponchartrain bounding on the east. The north and south boundaries of the spillway are formed by secondary levees or man-made ridges of land running the distance of the approximately 9,000-yard length of the spillway. Skyglow is minimized because of the distance from the city.

Figure 1

As Figure 1 indicates, we located a 60" general purpose searchlight at the lake end of the spillway on the corner of the north secondary levee. Here are also located the searchlight generator and a two-way radio for communication to the target area. About 500 yards down the levee from the light is located an artificial defilade consisting of a tarpaulin supported on a framework. Figure 2 shows a side view of the levee running down in the direction of the searchlight beam. Just off the levee are noted the elements of a transmissometer, this instrument being used to measure the density of the 500-foot sample of air separating the light element from the receiver.

The schema shown in Figure 3 illustrates the general arrangement of the experimental site. Approximately 7,000 yards from the searchlight there is a small natural amphitheater off to the side of the levee. This is surrounded by a relatively homogeneous background of thickly leaved trees and bushes. As shown, the subjects sit behind a recording table so arranged as to shield the target from their view. The target consists of an individual who stands behind a series of four dim red marker lights and takes his position behind some one of these lights for each trial according to a prearranged schedule. Note that the target-observer distance may vary from 25-100 yards.

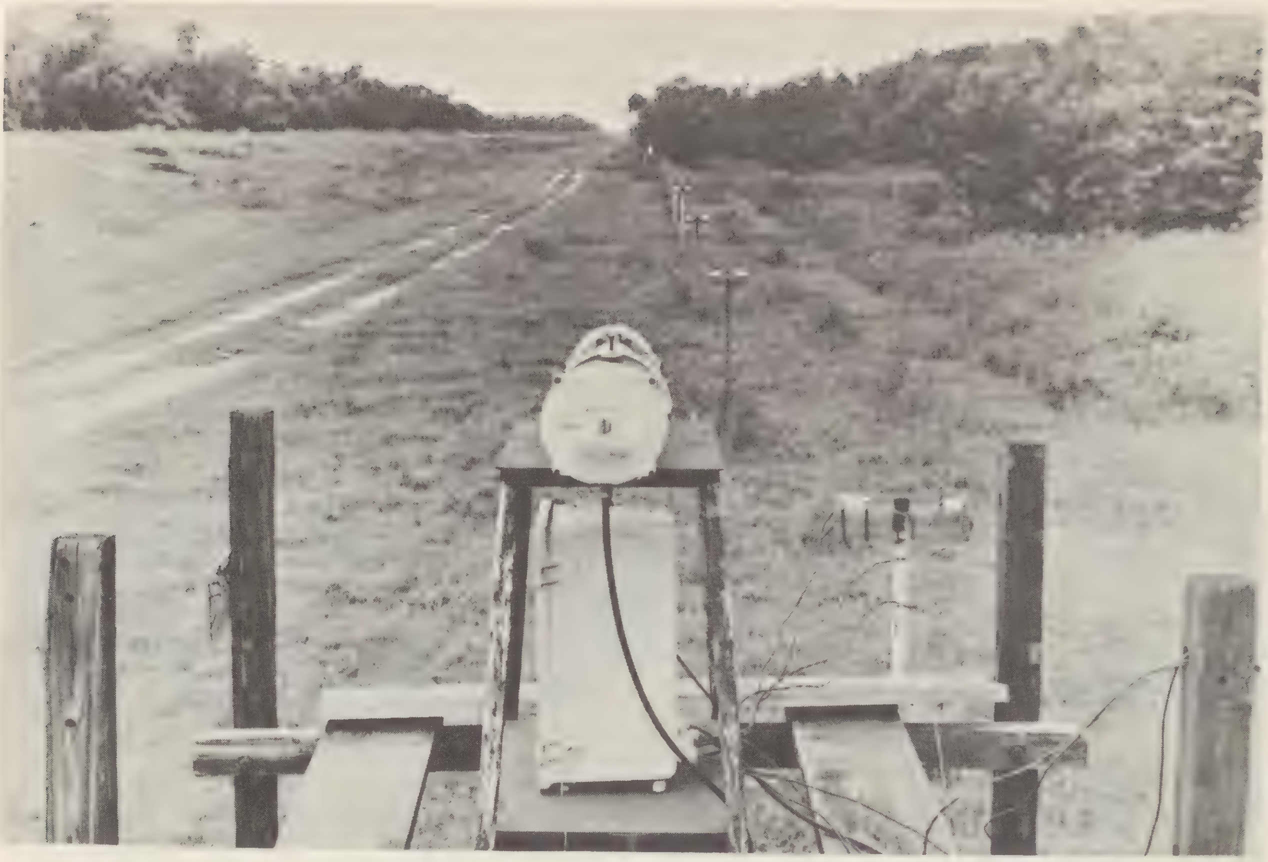

Figure 2

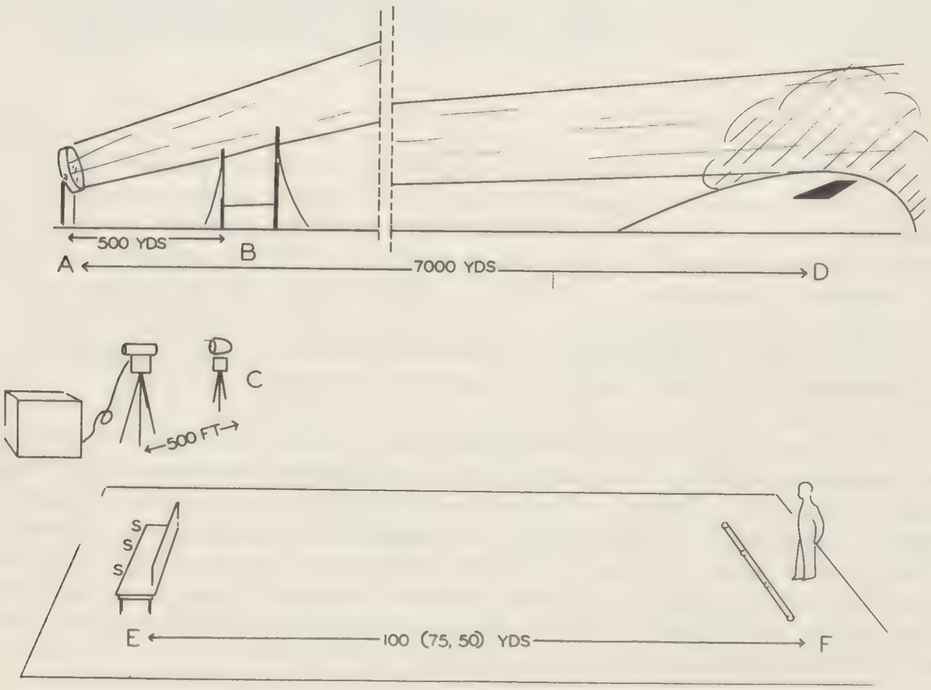

Figure 3

Figure 4 shows the target position. There is FM radio contact with the observer-control station. Also note the physical photometer used for monitoring. This is powered by a generator supplying a photomultiplier circuit in the jeep which is also equipped with a two-way radio for contact with the searchlight.

Figure 4

In Figure 5 we have shown three subjects behind the shield with the controller to the right. The next figure (6) shows the subjects viewing the target with the shield down and the controller in radio communication with the target.

Figure 5

The experiment consists now of testing the dark-adapted subjects following a training period in which they learn the nature of the target. The searchlight is set for some predetermined brightness by the use of opaque sectors and monitored by the physical photometer. The subjects are run through a sequence of 28 exposures to the target who assumes a position behind a different light each time. Each series of 28 exposures is run under one searchlight setting, and the subjects are forced to respond with the particular indicator position which the target seems to occupy. Each exposure lasts about 5 seconds and after each exposure the subjects are told by the controller what the correct position was. The exposures are controlled by lowering and raising the shield and the subject is instructed to use the visual technique which seems to work best for him during the interval of the exposure. Since there are 4 possibilities on each trial, the subject would be expected to get approximately 7 out of a block of 28 trials correct by chance alone. The threshold is defined as that level of illumination at which the subject is correct on 50 per cent of the trials above chance. The threshold is determined by plotting the percent of correct responses (corrected for chance) for each run against the level of illumination. This is plotted on probability paper and fitted graphically.

Figure 6

The next figure (7) shows a set of isofootcandle curves for a particular searchlight setting. The values for the footcandle levels were determined with the physical photometer which is more sensitive than the visual photometer in the field situation.

Threshold for detection of a human target at a distance of 75 yards[4] is approximately $.5 \times 10^{-4}$ "footcandles" as measured with the physical photometer. This means that an individual standing 75 yards from another individual would probably detect his presence at the ($.5 \times 10^{-4}$) line or anywhere behind.

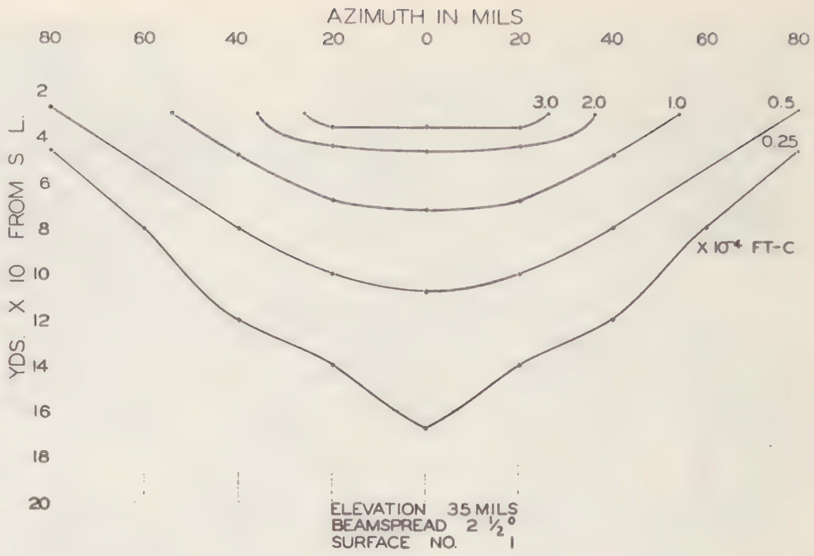

Figure 7

At 50 yards the threshold is about $.3 \times 10^{-4}$ "footcandles" and detection will probably occur at or behind the ($.25 \times 10^{-4}$) line.

At 25 yards the threshold is about $.15 \times 10^{-4}$ "footcandles" and detection will probably occur roughly in front of the $.25 \times 10^{-4}$ line.

These very gross thresholds are subject to the expected limitations of individual variation. Some subjects almost always report high scores, some almost always report low scores. The low performers seem to show more variability than the high performers. Increasing illumination does not necessarily increase scoring but the individual subject may often report the same score or even show a decreased score. Increased variability begins to appear at levels approaching 2×10^{-4} where the scotopic-photopic break begins.

Among the many variables which obviously render generalizations from the above results imprudent, we should like to raise again the question of the relation between photopic and scotopic vision in this range.

The use of a photopic or scotopic filter in the physical photometer, the spectral sensitivity of the dark-adapted eye (are we speaking of cones or rods, foveal or parafoveal?) in using the visual photometer calibrated against a light of one set of spectral characteristics and use in the field with a light of different spectral characteristics, the problem of changing from detection to recognition, etc., are all examples of practical import.

We have some experiments in progress based on spectral sensitivity differences between scotopic and photopic vision which we hope will give us a few clues to this problem. Further threshold studies are also in progress.

II. PHOTOMETRIC STUDIES

The physical data required for the photometric studies in this project are:

1. Measurements of the illumination which is produced by the atmospheric scatter of a sixty-inch carbon-arc searchlight beam.

2. Measurements indicative of changes in beam intensity attenuation and distribution due to varying atmospheric conditions.

3. Measurements of the illumination incident upon the target used in the psychophysical portion of the project.

4. Measurements of the contrast between the target and its background.

The amount of illumination resulting from beam scatter is dependent upon the relative position of the point of measurement with respect to the beam, the plane in which the measurements are made, and the beamspread. These independent variables can be manipulated easily. However, the illumination is also dependent upon certain atmospheric conditions which cannot be controlled. Since scatter is caused by the particles suspended in the atmosphere as well as by the molecular construction of the atmosphere itself, it is to be expected that any change in the type, amount, size, shape, or distribution of these particles might result in a change in the illumination received.

The selection of instruments to obtain these various measurements has been largely a process of trials. Visual photometers of the luminous-button type were used at the beginning of the project to measure the very low levels of illumination encountered. These photometers have the advantages of being mechanically simple and easily portable. However, it soon became apparent that these advantages are far outweighed by the disadvantages of inconsistency and time consumption. The variability of the results obtained by different operators and by the same operator at different times is great enough to cast doubt upon their usefulness.

Several physical photometers were investigated, of which only one met the requirements of sensitivity and/or stability. This instrument, a photomultiplier tube type photometer, was developed by Sweet and was suggested to us by Dr. S. Q. Duntley. Since the instrument is not commercially available in the form required, one was constructed at Tulane. It has proven to be highly dependable and stable. It is estimated that the data collected in a period of one month with this photometer would have taken between six months and a year had the visual photometers been used. One argument that has been advanced against the use of any physical photometer for very low level measurements bears mention. Since the physical photometer is incapable of shifting its spectral response characteristics in the same manner as the human eye between photopic and scotopic levels, it is argued that the instrument cannot evaluate the radiant energy incident upon it according to visual sensation. This, of course, is at odds with the definition of illumination. However, since the same instrument is used to measure the threshold illuminations for visual detection in our field situation as is used to measure illumination resulting from beam scatter, the information as to searchlight settings to obtain these threshold values should still be valid. Our instrument is equipped with a photopic correction filter.

It is interesting to note that while the visual and physical photometers were calibrated with the same standard lamp of color temperature approximately 2380 degrees Kelvin, the field measurements using the visual photometers run several times the magnitude of illumination as measured with the physical photometer. See Figure 8.

The measurement of atmospheric factors has been limited so far to visual range, measured with a transmissometer developed at the Bureau of Standards by Mr. Charles Douglas and associates, and general weather observations obtained from a Weather Bureau station located approximately ten miles east of the test site. The transmissometer samples a 500-foot section of the atmosphere near the searchlight. Due in part to this small sample, we have had almost no correlation between atmospheric transmission and illumination. We had intended to build an instrument which would measure polar scatter functions, but due to our futile experience with the transmissometer, we decided to measure the illumination at one distance from the searchlight on several clear nights; that is, no clouds or fog, in order to observe how much variation in beam intensity distribution could be expected. Over a period of five consecutive and similar nights (general weather observations approximately constant) the maximum change in illumination was observed to be on the order of 30 percent. When checked periodically over a time interval of approximately four months, the maximum change was observed to be about the same order of magnitude. It should be mentioned that a change of searchlight carbons can cause a variation in

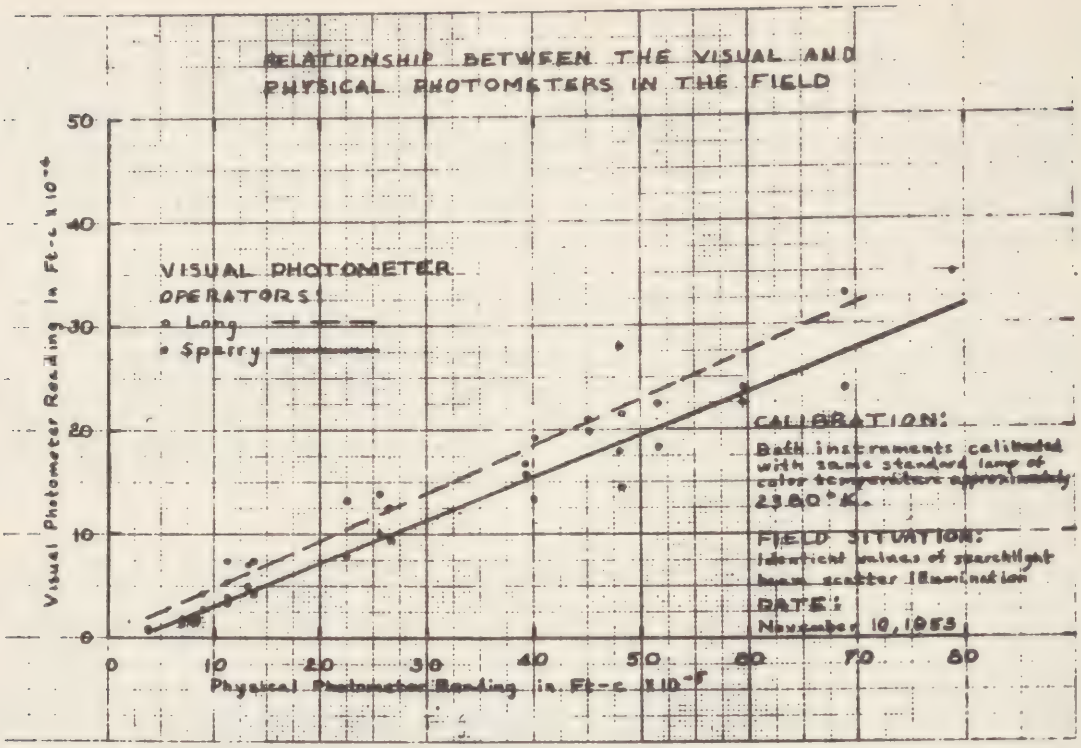

Figure 8

illumination of 10 percent. Polar scatter diagrams might be useful in correlating our results with measurements made in other geographical locations, and if time permits, the instrument will be constructed and samples taken.

The physical results are in the form of isofootcandle curves. The data for these were taken over a period of four clear nights. The general weather conditions; that is, temperature, relative humidity, dew point, observed visual range, etc., were approximately the same each night. Figure 9 shows the illumination incident upon a surface facing the searchlight, the beam elevation being 35 mils and the beamspread 1-1/4 degrees (in focus). Figure 10 shows the illumination incident upon the same surface, the elevation being the same, but the beamspread being 2-1/2 degrees. The trough from 0 to about 20 mils azimuth is caused by a similar trough in the candlepower distribution curve of the searchlight. Figure 11 shows the effect of raising the beam to an elevation of 50 mils. Figure 12 shows the illumination incident upon a surface facing away from the searchlight. The elevation in this case is 35 mils and the beamspread 1-1/4 degrees. Note that the illumination at similar distances from the searchlight is about 1/10 that on the surface facing the searchlight for the same searchlight positions. This gives some indication of the advantage friendly forces should have over the enemy when using this form of battlefield illumination. Illumination incident upon a side surface and a surface parallel to the ground are shown in Figures 13 and 14, respectively.

The illumination incident upon the target used in the psychophysical portion of the project is being measured with both types of photometers. The amount of illumination is controlled by placing pie-shaped opaque segments over the searchlight glass so as to change contrast conditions as little as possible.

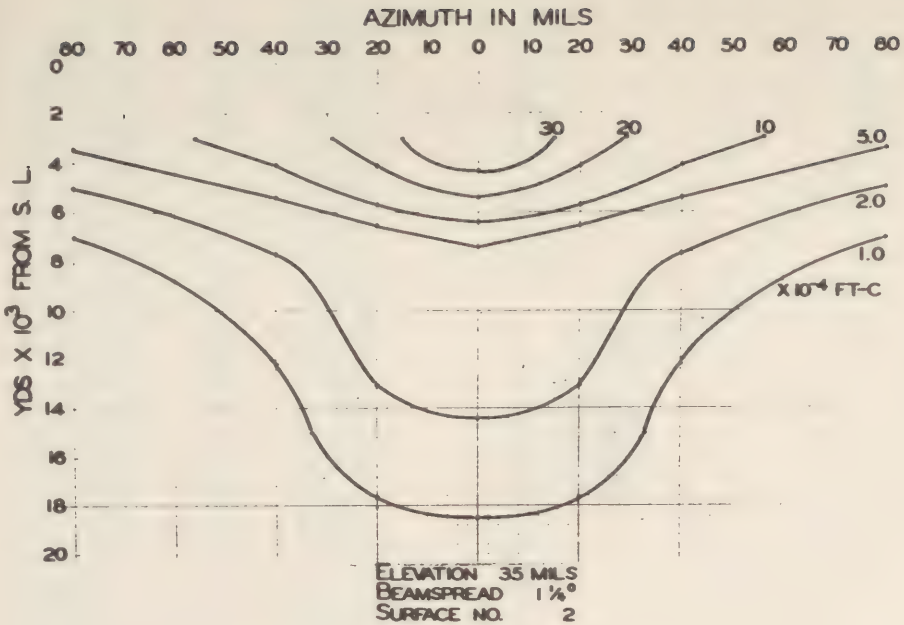

Figure 9

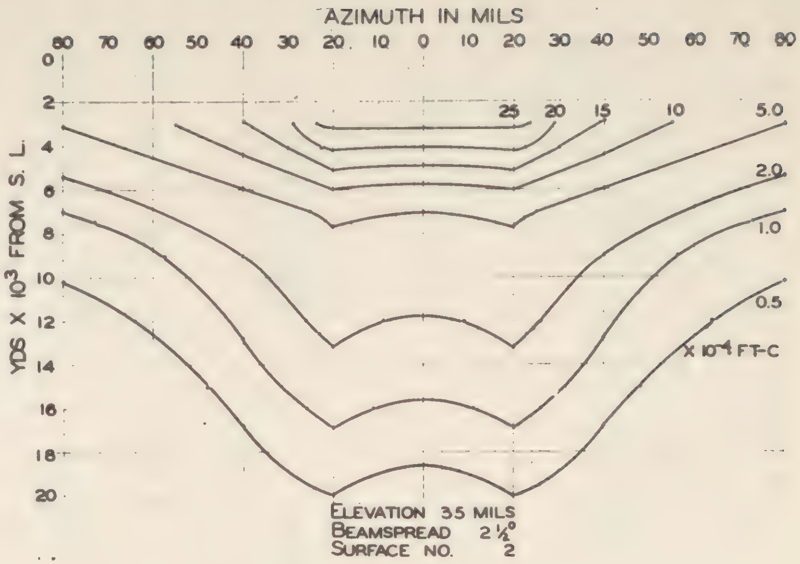

Figure 10

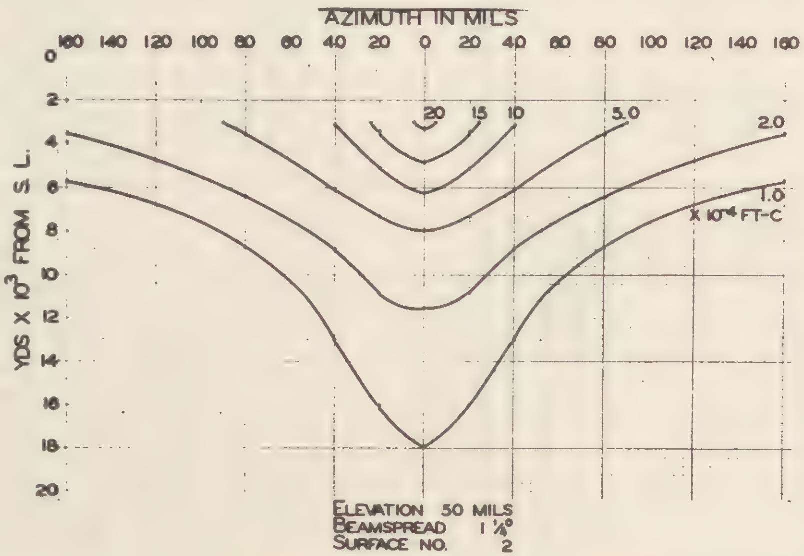

Figure 11

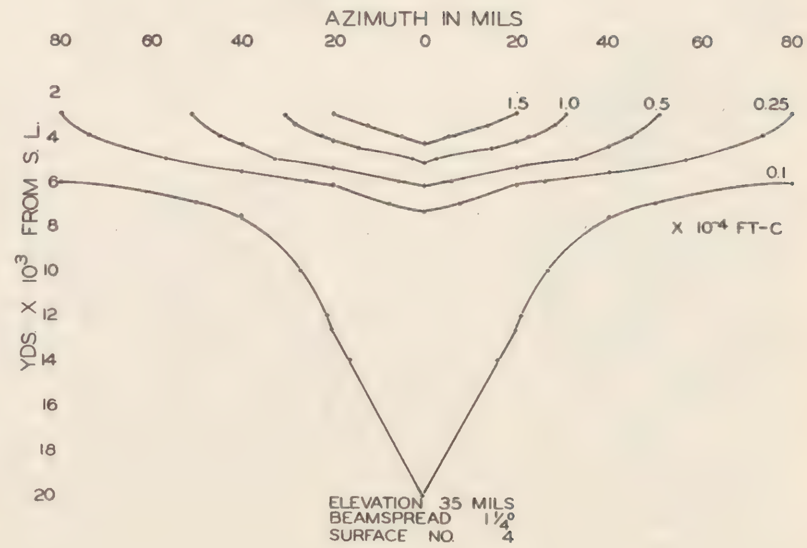

Figure 12

So far, we have not had much success in measuring the contrast between the target and its background. Neither the visual nor the physical photometer is sensitive enough to measure the brightness of the target or the background. Increasing these values of brightness would necessitate either changing the position of the beam, thereby changing the contrast situation; or changing the light source, which would result in a change in the spectral reflection of the target and background. A photographic method using a gray scale comparison has been tried and was unsuccessful due to the very long exposure times necessary. Another difficulty with this method arises from the fact that the gray scale should be calibrated with light of the same spectral energy distribution as the light reflected from the target and background. The accomplishment of this calibration with a fair degree of accuracy is extremely difficult. For the time being, we are limited to merely describing the contrast situation.

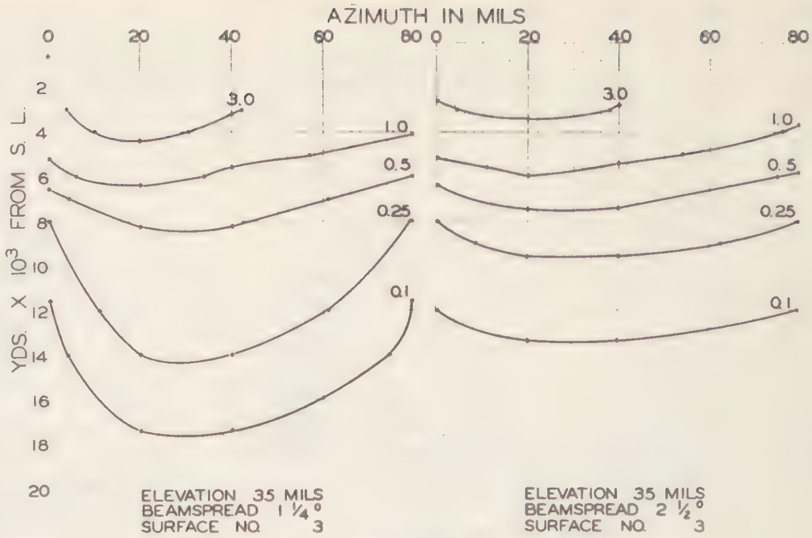

Figure 13

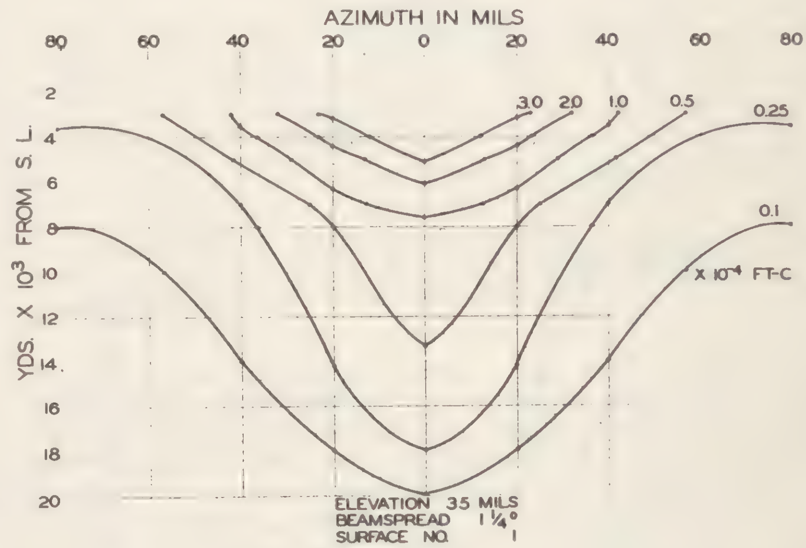

Figure 14

The psychophysical data have not been completed and analyzed; however from first observations, indications are that under certain conditions artificial moonlight can be beneficial up to 20,000 yards distant from the searchlight.

Discussion:

Mr. Middleton asked Dr. Bach if any attempt had been made to compare the psychophysical results of his experiment with calculations from the Tiffany data. Mr. Middleton questioned the necessity of outdoor field tests and wondered if the same results could be obtained by using the Tiffany data.

Dr. Bach stated that no such comparisons had been made but agreed that such comparisons should be made.

Dr. Blackwell expressed concern about the 10 to 1 difference found between values obtained with the photoelectric photometer and the visual photometer at low intensities. Dr. Blackwell asked if calculations had been made to investigate whether a 10 to 1 difference would be reasonable to expect in terms of the photopic-scotopic shift for the color-temperature involved.

Mr. Sperry replied that the 10 to 1 difference had not been checked by calculations, since the measurements between the two photometers had been made just a few nights earlier, and there had been no time for such calculations to be made. Mr. Sperry pointed out that, although 10 to 1 seemed to be a large difference, there is actually a large difference in the quality of the light. The light in the laboratory, 2380° K., is a reddish light, whereas in the field the light is almost blue. Mr. Sperry agreed, however, that calculations should be made to see if the 10 to 1 difference is reasonable.

THE ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES PROGRAM FOR THE DEVELOPMENT OF TANK SEARCHLIGHTS

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Introduction

The principal purpose of this paper is to indicate the extent of the problems involved in developing practical tank searchlights and in evaluating these searchlights. While we at the Engineer Research and Development Laboratories have a definite program aimed at solving these problems, we desire to obtain all the assistance possible in order to eventually arrive at the best searchlight with a minimum expenditure of time, funds and manpower, especially since these are so limited today.

The tank searchlight which has been standardized for present procurement is an adaptation of a commercial 18-inch incandescent searchlight. It has a 19-1/2 inch diameter, pressed-aluminum mirror with an Alzak finish and uses a 2000-watt, 28-volt, 100-hour-life, tungsten-filament lamp. The shutter is provided to eliminate the afterglow of the filament when the lamp is switched off. Detection ranges up to 1200 yards have been reported for this light but under average to good conditions the effective maximum range is considered to be 1000 yards.

Determination of Requirements

Major Fellows, of Army Field Forces Board No. 2, has made a study of the tactical performance requirements for a desirable tank searchlight. These requirements have been incorporated into a set of Military Characteristics which are now in the process of being coordinated prior to adoption. The performance requirements are as follows:

Maximum detection range in center of beam. . .	1500 yards
Maximum detection range at 4^{o} to right and left of center	1200 yards
Target (hull-down tank) area	60 sq. feet
reflection factor	8 per cent
Background reflection factor	6 per cent
Visibility	11 miles
Viewing optics in searchlight tank	10 power
Power available	2-1/2 kilowatts total

We have Major Fellows to thank for what I think is a rather unusual achievement. For the first time, to my knowledge, the tactical requirements for a military searchlight have been carefully specified in advance of a new development. Generally, when a searchlight is to be developed for any application the desired performance is expressed in terms of range, but defining the range of a searchlight is usually like defining the length of a piece of string. Here, enough information has been given, and laid, I believe, on sound doctrine, to make possible an intelligent approach to the problem of designing the desired searchlight.

Before we can start the design, the above requirements must be converted to a candlepower distribution requirement. In order to solve this problem the services of the

Vision Committee were enlisted. The results of the Vision Committee study were reported to the Committee a year ago by Dr. Blackwell, and were later published in a classified report by H. Richard Blackwell, S. Q. Duntley and Wilfred M. Kincaid, dated March 1953. Copies can be made available by the Secretariat of the Vision Committee to interested organizations authorized to receive such documents.

During the progress of the Vision Committee's calculations it became apparent that the candlepower requirements for detection of a target of .08 reflection factor against a background of .06 were too high to be realized within the power limitations imposed. However, it was our opinion that this might be a tougher detection problem than might actually be encountered. While a freshly painted tank might have a reflection factor of 0.08, in combat a tank would soon be covered with dirt which might raise the reflection factor to an average of 0.13. With this assumption, the computed candlepower requirements are lowered to more nearly practicable values.

From an analysis of this report it may be concluded that a searchlight having a peak intensity of 10 million candles, and a horizontal spread of 4 degrees to 25 per cent of peak candlepower, will meet most of the detection requirements.

Investigations

We have therefore chosen these candlepower requirements as our immediate goal. However, reasonable as they may seem, actual accomplishment is another matter. The beam dimensions of 8 degrees horizontal and 1 degree vertical amount essentially to a spread beam. This spread can be obtained in two ways, either by using a paraboloidal mirror with an elongated source, or by using a spherical or disc source and optical spread. Optical spreading can be accomplished by a cylindrical front cover lens, or by a specially figured reflector. The disadvantage of the elongated source is that the ends of the source are so far from the focus of the reflector that the edges of the beam are defocused and low in candlepower. This accounts for the dumbbell-shaped beam pattern obtained with this combination. Optical spreading has disadvantages, too, since the cylindrical lens cover glass interposes an optical element to absorb, scatter and waste light, and in addition it is vulnerable to breakage. Specially figured reflectors are difficult to make and the best are generally of such inaccuracy that they are inefficient when used with small, bright light sources.

In the attempt to solve this problem we have investigated a number of light sources, each of which possesses at least one serious disadvantage.

Figure 1 shows candlepower distributions obtained with several of these sources. All of these distributions were obtained using a precision-type, glass paraboloidal reflector, 18 inches in diameter and 8 inches in focal length. The candlepower requirements are shown by the straight lines drawn downward from the axial ordinate of 10 million candles. The 1 kw BH-6 mercury capillary arc meets the peak candlepower requirement but is deficient in both horizontal and vertical spread. This spread can be improved somewhat by using a reflector of shorter focal length. The extremely small diameter of this source (less than 2 millimeters) puts a high premium on reflector accuracy. A feature of the capillary

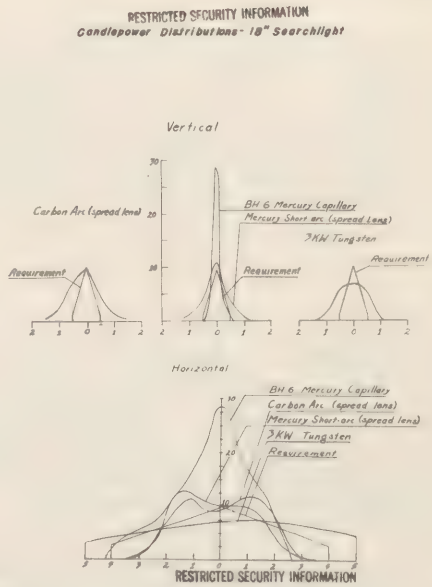

Figure 1

lamp is that it has no afterglow, thus eliminating the need for a shutter. This lamp, in addition to the complication of requiring dc to ac conversion and voltage step-up, requires high-pressure air-cooling. In fact, approximately as much power is required to cool the lamp as is required to heat it! This lamp also has an uncertain life which is shortened by flashing.

The small high-intensity dc carbon-arc lamp is a small source which requires a spread lens. Here it is shown as barely meeting the peak requirement while being deficient in horizontal spread. While it will operate satisfactorily from 28-volts, dc, it will not operate at lower voltages and adequate regulation cannot be expected from the tank's electrical system. It would also require some sort of magazine feed for continuous operation. It can be flashed. The recently developed compact, or short-arc, mercury lamp is very close in size and brightness to the dc carbon arc and gives a similar distribution. It is capable of being flashed with special equipment and has a reasonably long life. However, it requires a minimum of 5-minute preheat time. In order to have the light available instantly when desired, stand-by operation is required. This is undesirable especially in present-day tanks. It also requires high-voltage starting equipment.

The last source shown is the 3-kilowatt tungsten lamp. This lamp will give approximately twice the candlepower of the 2000-watt lamp now used, largely obtained by virtue of a design life of 10 hours. It has a single-coil filament which gives a smooth beam pattern. We believe that the peak candlepower requirement can be met by using a larger, longer focal-length reflector. The biggest advantage of the tungsten lamp is its simplicity, eliminating the need for dc to ac conversion, transformers or starting circuitry.

We are also considering other light sources, including xenon-arc lamps and ac carbon arcs both of which will require optical spread. The xenon-arc lamp is similar to the compact mercury lamp but has lower brightness. It features quick striking and warm-up but is hazardous to use since it is under high pressure, even when cold.

A suitable ac carbon arc is not yet available; however, in principle it shows considerable promise, and problems in development do not appear too difficult. The arc is formed between two positive carbons, both facing the reflector. Both craters are of equal brightness.

While spread can be achieved by the use of a cylindrically fluted front lens, we hope that it can be incorporated in reflectors for use with the small sources. One method which shows promise is to "squeeze" the reflector along the vertical diameter. The resulting contour is a parabola of shorter focal length in the vertical plane and a parabola of longer focal length in the horizontal plane. When the lamp is set at the focus of the vertical parabola it is out of focus for the horizontal parabola, resulting in horizontal spread. Another obvious method is to cut a reflector into two or more sections which can be offset slightly to give horizontal spread.

Blackwell, Duntley, and Kincaid, in their report emphasize the importance of even small amounts of separation between searchlight and viewer. This, of course, is well known, but is quantitatively shown by their computations. However, many considerations dictate the choice of a location for a searchlight on a tank. The location shown in Figure 2 is that presently used and was chosen because it requires neither traversing or elevating mechanisms and because on this tank, the M-46, it is least vulnerable to the rearward blast from the muzzle brake.

Reports from Korea on the use of the searchlight consistently mentioned the obstruction that the light presents to the tank commander's field of view and field of machine gun fire. Since the new searchlight may be larger than this one we felt it important to make

a study of the effect of searchlight shape, size and location on the tank commander's field of view. We found that a box 20 inches high and 30 inches wide may be located on the turret just to the left of the gun shield where it will present a minimum of obstruction to the tank commander's view. This location can now be used because newer muzzle brakes are designed to give less rearward blast. This location will improve the tank commander's view because it will give him some vertical separation as well as more horizontal separation. Increased lateral separation will also be given to the tank gunner. The light will still traverse with the turret, but linkage to the gun will be required to provide tracking in elevation. Better viewing would be afforded by raising the light several feet above the turret but such a location would interfere severely with the tank commander's machine gun and would undesirably increase the tank silhouette.

Figure 2

Future Program

From the foregoing discussion it should be apparent that there are a variety of possible combinations of source and reflector with no clear-cut choice for any particular combination. It is also barely possible that still another source or reflector design may be suggested to us, which may solve all the problems at once.

Our program at present is to develop under contract, engineering models of two searchlights, one with a capillary mercury lamp and the other with a tungsten lamp. Each will be used with a reflector of optimum size and focal length. We are also sponsoring further development of carbon arcs, compact mercury lamps and xenon lamps in order to obtain more data about them, in the hope of overcoming their several disadvantages. We will continue to experiment with various reflector configurations in order to determine the optimum reflectors for use with each source.

Proposed Field Tests

To compare properly the performance of different searchlights, to determine whether a particular searchlight actually will give the required performance, and to demonstrate performance to interested observers, some sort of a field testing set-up is necessary. We are, we hope, aware of most of the objections to field testing—lack of controlled conditions, etc.; but we propose to reduce the uncertainties as much as possible. Figure 3 is an artist's sketch of our proposed layout. For a background we will stretch target cloth between two telephone poles. The target, which must be about 8 feet square, will be made of a light material which can be exposed to view quickly and removed as desired. Ranges at various distances are not readily available but we are principally interested in a range of 1500 yards, which is available. The searchlight and viewer can be set at various

lateral and vertical displacements to simulate the various positions these will have on a tank. Observations will be made by the forced-choice method, or by observers indicating awareness, depending on whether we are making a test or merely demonstrating.

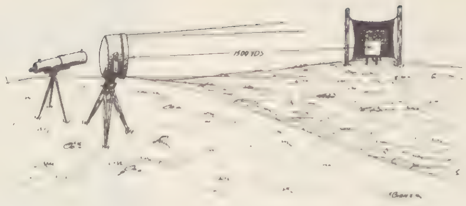

Figure 3

Backgrounds and targets can be varied in reflectance and the searchlight intensity can be varied by voltage and/or diaphragms. All conditions can be controlled except the most important, the atmospheric scatter. All that can be said here is that the transmission and the scatter can be measured, assuming homogeneity over the entire range. Since the requirements are based on conditions of good visibility, which around Fort Belvoir occur quite frequently, we feel that the variation from this condition can be held to a minimum.

We hope also to make photometric measurements of background and target brightness as seen through the searchlight beam. These data, together with photographs which might be taken of typical targets, would be useful in the event that we might wish to bring this problem back into the laboratory.

We would like to scale this entire test down to ranges, target sizes and backgrounds easier to handle, but I know of no way to duplicate the back scatter in 1500 yards of atmosphere, except to actually have 1500 yards of atmosphere.

My hope, in this presentation, is to stimulate suggestions from those present. Your comments are invited, together with suggestions as to how we can make this field test work.

Visual Acuity Under Mercury Light

Before closing this paper, however, I would like to present still another problem which we would like to solve in these tests. J. Funke and P. J. Oranje in their book Gas Discharge Lamps present curves which indicate that visual acuity is higher under mercury light than under an equal illumination of incandescent tungsten light. Indeed, at a demonstration held at Fort Knox last May it seemed that a mercury light did have much better performance over a tungsten searchlight than was indicated by their relative candlepowers. However, at a later demonstration at Fort Belvoir, this effect was not observed. It was suggested by one engineer that the effect, if any, might be caused by fluorescence of foliage. We have not observed that foliage fluoresces to such a significant extent. Funke and Oranje attribute the effect to the monochromatic nature of visible mercury light. The mercury lamps, for which their curves are given, while rated as high-pressure lamps, are of the H-4 type which do not operate at nearly as high pressure as the mercury lamps proposed for searchlights. At the pressures at which our lamps operate, considerable continuum is observed. I would appreciate any comments on possible increases in visual acuity under mercury lamp illumination that any of you have to offer.

Discussion:

Mr. Middleton asked Mr. Bartelt if he had consulted the work done by Chesterman and Stiles in England during the war, a long and brilliant report which is contained in A Symposium on Searchlights, published by the I.E.S. in London about 1945 or 1946. Mr. Middleton said that Chesterman and Stiles conducted a great many experiments of exactly the same sort as those done by Mr. Bartelt. However, since the Navy was doing the experiments, they used ships rather than tanks for targets. Experiments were done on a full-size scale and by calculation, with remarkable agreement.

Mr. Bartelt said that they had managed to get a copy of A Symposium on Searchlights, and intended to take full advantage of this report.

Dr. Hulburt expressed the opinion that there is a point to be made for field experiments. He pointed out that laboratory criteria and field criteria for detectability are different, that the field criteria are always very vague, and that about the only way field criteria can be determined is by means of field experiments.

Dr. Hulburt extended his earlier remarks about laboratory and field experiments. He noted that the constant question of laboratory vs. field tests is a dual one. He went on to say that both laboratory and field tests ought to be done, because they serve different purposes and answer different kinds of questions. For example, the way to compare two searchlights is in the laboratory, under laboratory conditions. To find out which searchlight will pick up a man better, one does not take a man and the two searchlights out in the field to get the answer. First, one establishes the requirements for picking out the man, then takes the two searchlights into the laboratory and tests them to find out which is better under the ideal target arrangements. On the other hand, other tasks require field tests.

Dr. Blackwell asked Mr. Bartelt what his reaction had been to the statement made during the demonstrations that there seemed to be little advantage in moving the observer off-axis from the beam. Although all the calculations suggest that this variable is very important, statements made by Major Fellows and confirmed by General Collier, indicate that this is not important. Dr. Blackwell suggested that Mr. Bartelt might care to comment on this seeming discrepancy between what one might expect on the basis of theory and what is reported by some operational personnel.

Mr. Bartelt said that he had been equally surprised by these statements. He thought there was an advantage in separating the searchlight from the observer just as much as possible. Lateral separation does help to some extent. Vertical separation, of course, is preferable, but involves mechanical difficulties and also cuts down the tank commander's field of view and field of fire.

THE DEVELOPMENT OF A METHODOLOGY FOR THE DETERMINATION OF VISUAL STANDARDS FOR NAVY BATTLESTATION ASSIGNMENTS*

Joseph Tiffin
Purdue University

Basic Objective

The objective of this research is stated in a statement resulting from a joint meeting of representatives of the Bureau of Naval Personnel, the Office of Naval Research, and the Purdue Research Foundation held in July, 1952. This statement is as follows: "The basic objective of research contract N7 onr-39423 is to develop methodology for establishing vision standards for selected battlestation assignments aboard various types of naval vessels."

Several methods of undertaking the research were considered:

Method 1. Arbitrary establishment of visual standards by judgments of trained and/or professional personnel. This method was discarded because a search of the literature revealed no studies evaluating the effectiveness of the method.

Method 2. Trained and/or professional personnel arbitrarily establish visual standards based on subjective evaluation of data obtained from descriptions of the visual features of the job that have been reduced to physical measurements. The physical measurements include such factors as distance, visual angles subtended at the eye, frequency of operation, brightness contrast and level of illumination. This method, unless followed by validation studies, would seem to result only in approximate, but unproved, standards.

Method 3. Experiments so designed that the visual tasks of the jobs be performed by trained personnel possessing different levels of visual skills. Performance on the job is measured, and relationships existing between job performance and visual skill levels are statistically determined. From these relationships the visual skills necessary for satisfactory job performance are determined in a quantitative manner.

Method 3 was followed in the present research. The first job sample test was constructed from a Mark VI Computer. Covers were made for each of eleven dials on this computer. The task of the subject was to uncover the dials (one at a time) and report the reading on which the dial was set. Using this procedure, the eleven visual tasks (dials) were successively presented to the subject.

Using this job sample, two separate measures of job performance were available—time and accuracy. The time score was the time in hundredths of a minute required to read the dial. The accuracy score was obtained by comparing the reading given by the subject with the reading on which the dial was set. The accuracy scores were either right or wrong. No attempt was made to evaluate the amount of error when an incorrect reading of the dial was given.

In the initial experimentation to develop and try out the job sample approach, nine industrial psychology graduate students were used as subjects. The results showed that performance on the job-sample could be measured and statistically evaluated. The next phase of the experimental work was then undertaken.

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*A report to the Armed Forces - NRC Vision Committee of research done by the Purdue Research Project N7 onr-39423, NR 152, 129.

Phase II consisted of testing 104 subjects on a job-sample test developed on an anti-aircraft fire control unit. The test was of the same type used initially in the exploratory study, and consisted of visual tasks (dials). Each subject repeated each dial reading ten times. Separate time and accuracy scores were recorded for each reading. In addition, each subject was given the Bausch and Lomb Ortho-Rater vision test. It was hoped to find a significant relationship between the Ortho-Rater vision test scores and performance on the job sample. However, no relationships were found, probably because of the restricted range in the vision scores of the group available as subjects. This phase of the work, however, made it possible to determine the reliability of the job sample. The time scores were found to have a reliability of .95. The reliability of the accuracy scores, however, was only .43. This latter low reliability was undoubtedly due to the fact that very few errors in reading the dials were made.

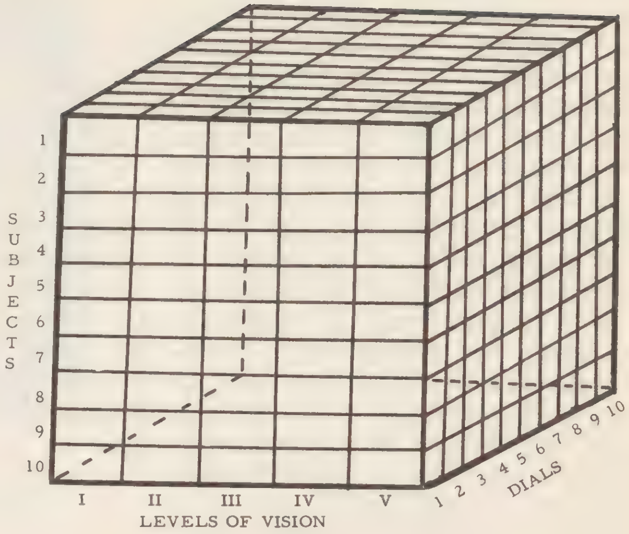

Figure 1. Schematic Diagram of the Factorial Design Used in Phase III. Each Cell Represents Ten Dial Readings.

The results of Phase II of the experimental work made it clear that a greater range of vision would have to be obtained to effectively evaluate the job sample approach. The most convenient and reasonable method of obtaining this range was suggested by Dr. Henry Imus and Dr. Glenn Fry of the Armed Forces-NRC Vision Committee. This consisted in using crossed-cylinder oblique lenses of varying power to reduce the visual acuity of the subjects used in the experiment. Accordingly, Phase III of the work was begun. This consisted of a factorially designed experiment with the following variables:

1. 10 subjects
2. 5 levels of vision
3. 10 dials (i.e., stations)

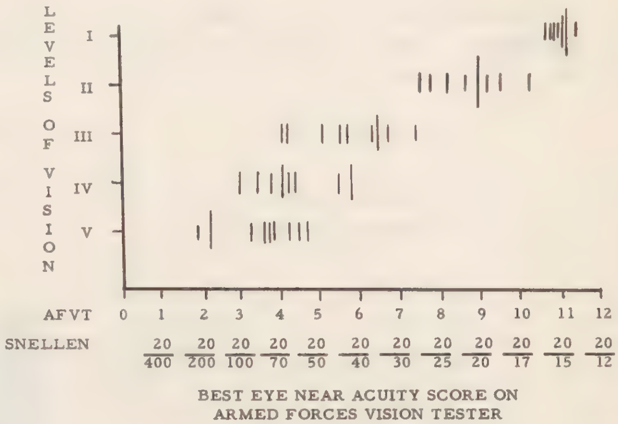

Figure 2. Average Near Acuity Score of Ten Subjects at Five Levels of Vision (Using Each of the Five Sets of Crossed-Cylinder Lenses).

The experimental design is shown schematically in Figure 1. The ten subjects were chosen from 15 who were refracted by a graduate optometrist. The ten chosen were those who had the least visual difficulties without correction and could be corrected to 20/15 or better at near point with an appropriate correction. Appropriate corrections were prescribed and used throughout the experiment. No subject who needed an appreciable amount of astigmatic correction was selected since the clip-on crossed-cylinder lenses used to reduce visual acuity produced an astigmatic error and atypical performance might result if a subject normally possessed any very great degree of astigmatism. The near point visual acuity of the subjects used at each of the five levels of acuity induced artificially for the experiment is shown in Figure 2.

Three of the 10 stations (dials) used are shown in Figure 3. The job sample was essentially the same as that used in Phase II. The 10 dials, or visual tasks, in the test represented all the dials contained in an Anti-Aircraft Fire-Control Unit. The subjects performed on the test from the position normally assumed by operators of the equipment, as shown in Figure 4. Each of the 10 subjects was thoroughly trained on each of the dials in the job sample before the experiment began. In the experiment, each of the subjects performed 10 times on each dial under each of the 5 levels of vision. The 50 cells of 10 randomized readings given to each subject were randomly ordered. The vision of the subjects was tested by the Armed Forces Vision Tester and the Bausch and Lomb Ortho-Rater before the administration of each cell. The experiment was conducted over a period of 10 days and each subject was used for approximately 1-1/2 hours per day.

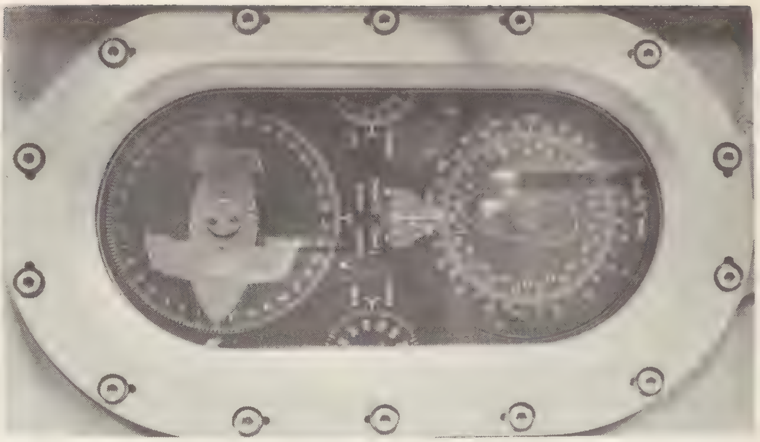

Figure 3. Representative Visual Tasks of the Job Sample Used in Phase III.

The data were first analyzed to determine the reliability of performance on the job sample test. The obtained odd-even reliability coefficients (corrected by Spearman-Brown prophecy formula) are given in Table 1.

TABLE 1

Reliability of Performance Scores on the Job-Sample Test

Dial No.	Reliability (Time Criterion)	Reliability (Accuracy Criterion)
1	.87	-.11
2	.92	.72
3	.84	.00
4	.94	-.15
5	.69	-.09
6	.95	.69
7	.98	.34
8	.90	.66
9	.91	.71
10	.92	.66
TOTAL TEST	.96	.59

Figure 4. Subject Performing on the Job-Sample Used in Phase III.

The obtained reliability coefficients of time performance were more than adequate for each dial and for the total test. The obtained reliability

coefficients of accuracy performance were low. However, the latter result was probably due to the fact that on five of the dials the variability of performance on the accuracy criterion was so small the reliability could not be measured and the obtained reliability coefficients are either an indeterminate number or a random fluctuation from zero. Because in these cases there were so few incorrect readings, it appears safe to assume that the reliability coefficients are not a true measure of reliability, and that if the experiment were to be repeated, similar results would be obtained.

Both the time and accuracy scores were then analyzed using the factorial analysis of variance. In both analyses the data were transformed in order to meet the assumptions of the model. The analyses are given in Tables 2 and 3.

TABLE 2

Analysis of Variance of Time Scores

Source of Variation	df	Sums of Squares	Mean Square	F-ratio
Between subjects	9	3.9127	.4347	68.23*
Between levels of vision	4	14.3768	3.5942	89.82*
Between dials	9	31.7613	3.5290	109.01*
Subjects x levels of vision	36	1.4404	.0400	6.28*
Subjects x dials	81	2.6222	.0324	5.08*
Dials x levels of vision	36	2.8773	.0799	4.48*
Subjects x dials x levels of vision	324	5.7790	.0178	2.80*
Within cells	4500	28.6761	.0064	
TOTAL	4999	91.4458		

*Significant beyond the 1% level.

TABLE 3

Analysis of Variance of Accuracy Score

Source of Variation	df	Sums of Squares	Mean Square	F-ratio
Between subjects	9	3,069.20	341.03	7.02*
Between levels of vision	4	6,162.80	1,540.70	21.09*
Between dials	9	12,357.70	1,373.08	14.54*
Subjects x levels of vision	36	2,630.33	73.07	1.50**
Subjects x dials	81	7,647.38	94.41	1.94*
Dials x levels of vision	36	5,705.04	158.47	3.26*
Subjects x dials x levels of vision	324	15,749.37	48.61	
TOTAL	499	53,321.82		

*Significant beyond 1% level. **Significant beyond 5% level.

Although the significance of the difference between the means for each of main effects and each of their 1st and 2nd order interactions was tested, the effect of vision upon performance and differences in performance on the different dials were of the greatest importance for the purposes of this study. In both analyses, the hypothesis of no mean difference for each of these two effects was rejected, resulting in the conclusions that vision was related to performance, and that there was a real and significant difference in performance on the difference types of dials.

On the basis of these results it was decided to develop performance curves representing the relationship between vision and performance for each dial. Because each of the visual tasks in the job sample was within the range of nearpoint acuity, curves representing the relationship between that visual function, as measured by the Armed Forces Vision Tester, and performance were developed. In order to develop a logical basis for such curves, a method of averaging was used in developing the curves. This resulted in a plot of 50 time scores for each dial to which both free-hand and mathematical curves were fitted. Using the least squares criterion, the mathematical function

$$y = \frac{a}{x} + b$$

provided the best fit to the data for all but two dials. On these two dials a straight line provided the best fit, although the least squares difference between the fit of the two curves was very small. Therefore the inverse function was fitted to the time data for all dials. The formula used was

$$t = \frac{a}{v} + b$$

where $\underline{t}$ is time score, $\underline{v}$ is best eye near visual acuity score on the Armed Forces Vision Tester, and $\underline{a}$ and $\underline{b}$ are constants.

Comparison of the free-hand and mathematical curves showed them to be essentially the same. The curves fitted by the mathematical function did not necessarily describe the nature of the relationship better than the free-hand curves, but are used as a convenient means of presenting the data. The curves for the easiest and most difficult dials in the job-sample are given in Figure 5. (Dials 3 and 7 on time.) An illustration of the manner in which the curves fit the data is provided in Figure 6.

Accuracy performance curves were also developed for each dial. However, only free-hand curves were developed for these curves as it had been conclusively shown in developing the time curves that free-hand and mathematical curves would be essentially the same. The curves for the easiest and most difficult dials are shown in Figure 7. (Dials 3 and 7.)

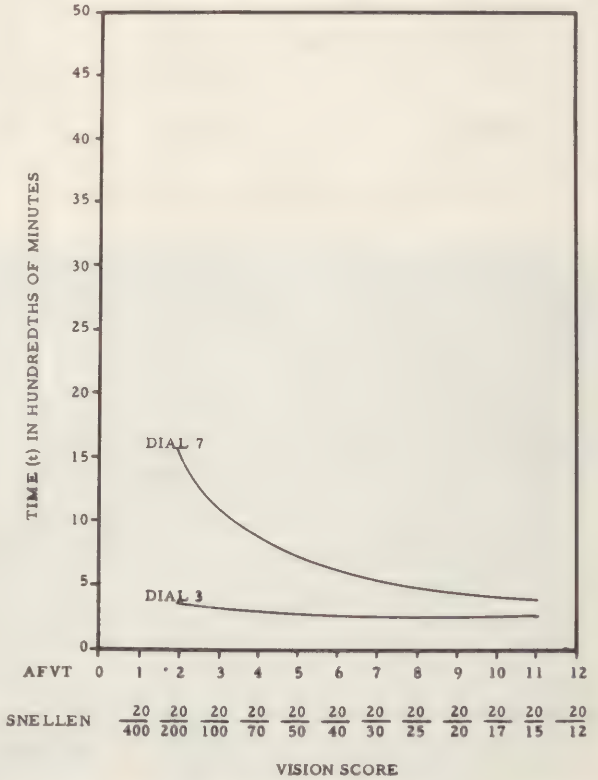

Figure 5. Relationship Between Near Visual Acuity and Time Performance on the Easiest and Most Difficult Dials in the Job Sample (Phase III).

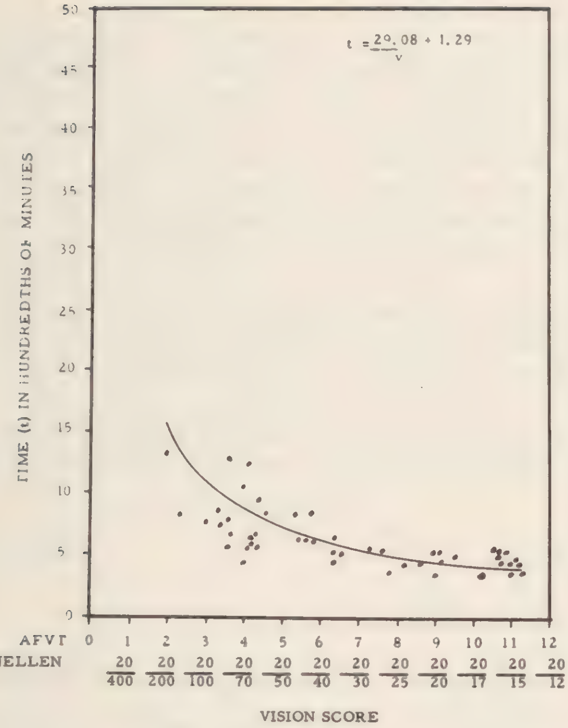

Figure 6. Fit of Inverse Curve to Time Data for Representative Dial in Job Sample (Phase III).

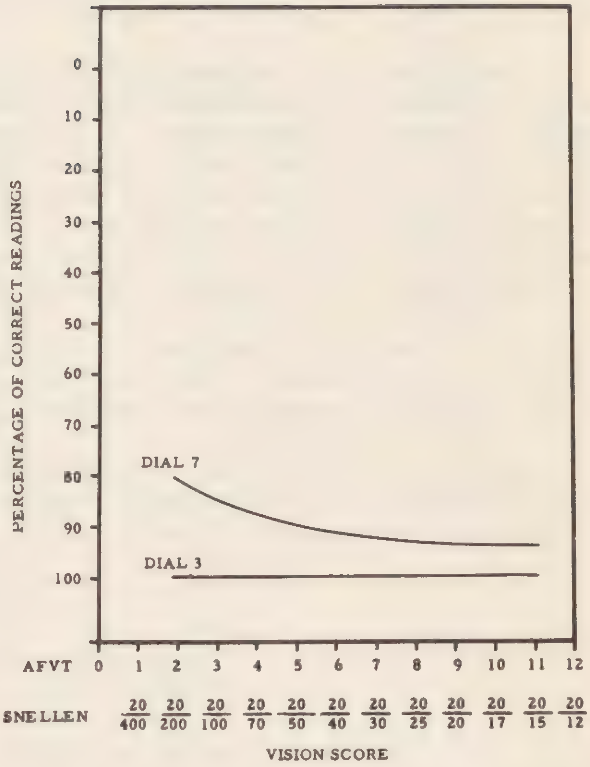

Figure 7. Relationship Between Near Visual Acuity and Accuracy Performance on the Easiest and Most Difficult Dials in the Job Sample (Phase III).

Due to the significant interaction of dials and levels of vision, as shown in both analyses of variance, performance on one dial cannot be compared with performance on another. A curve represents the relationship between vision and performance on only one visual task and cannot be generalized to other visual tasks. Therefore, in evaluating performance on a dial, performance on the successively lower levels of visual acuity should be compared with performance at other levels of visual acuity on that task. This further means that curves must be developed for each visual task. On the basis of the results of this study, free-hand curves, drawn by an experienced investigator, may be used to show the relationship between vision and performance. This reduces the task to a routine collection and analysis of data.

In order to provide additional information concerning the methodology evaluated, Phase IV of the research was initiated. This study was specifically designed to extend the research conducted in Phase III. Two problems were investigated: (1) the effect of different levels of illumination on the relationship between artificially altered vision and performance on a job sample, and (2) the effect of distance from the task on the relationship between artificially altered vision and performance on a job sample.

If by reducing illumination, the performance of subjects at all levels of vision was reduced uniformly, it could be concluded that performance curves developed under one level of illumination would be parallel to curves of performance at other levels of illumination. However, if the curves for different levels of illumination were not parallel, the level of illumination would have to be carefully considered when deriving visual standards.

The same reasoning holds for the effect of distance from the work on the performance curve.

This study was designed and the data analyzed in a similar manner as in Phase III. The job sample consisted of one complex dial contained in the Mark VI Computer.

The experiment was designed and conducted so that the results could be analyzed using the factorial analysis of variance technique. There were 10 subjects, 5 levels of vision, 5 levels of illumination, and 3 distances which gave a total of 750 cells. There were 10 readings in each cell. Each subject performed under all combinations of vision, illumination and distance. The 10 subjects were the same ones used in Phase III. The method of altering vision was the same. The distances of the dial from the subjects' eyes were 12", 20", and 30". The 5 levels of illumination varied from approximately 570 to .25 footcandles. The brightness varied from approximately 80 to .03 foot lamberts.

The reliability of performance on the job sample was estimated by correlating odd versus even replications. The reliability coefficients (stepped up by Spearman-Brown prophecy formula) were .96 for the time scores and .85 for the accuracy scores.

Both the time and accuracy scores were analyzed by the factorial analysis of variance. The data were transformed to meet the assumptions of this model. The results of the analyses are given in Tables 4 and 5.

TABLE 4

Analysis of Variance of Time Scores

Source	df	Sum of Squares	Mean Square	F-ratio
Subjects	9	7.5822	0.8425	156.02*
Levels of vision	4	27.8834	6.9708	49.16*
Distance	2	13.2851	6.6426	265.70*
Illumination	4	7.7194	1.9298	119.86*
Subjects x level of vision	36	5.1056	0.1418	26.26*
Subjects x distance	18	0.4501	0.0250	4.63*
Subjects x illumination	36	0.5807	0.0161	2.98*
Levels x distance	8	6.6278	0.8285	50.83*
Levels x illumination	16	3.0282	0.1893	16.90*
Distance x illumination	8	1.0544	0.1318	11.98*
Subjects x level of vision x distance	72	1.1740	0.0163	3.02*
Subjects x level of vision x illumination	144	1.6180	0.0112	2.07*
Subjects x distance x illumination	72	0.7912	0.0110	2.04*
Level x distance x illumination	32	0.9448	0.0295	2.42*
Subjects x level of vision x distance x illumination	288	3.5323	0.0122	2.26*
Within cells	6750	36.2504	0.0054	
TOTAL	7499	117.6276		

*Significant beyond 1% level.

TABLE 5

Analysis of Variance of Error Scores

Source	df	Sum of Squares	Mean Square	F-ratio
Subjects	9	11,177.29	1,241.92	10.13*
Levels of vision	4	68,523.92	17,130.98	47.74*
Distance	2	59,940.44	29,970.22	125.99*
Illumination	4	14,417.81	3,604.45	35.66*
Subjects x level of vision	36	12,917.65	358.82	2.93*
Subjects x distance	18	4,281.79	237.88	1.94**
Subjects x illumination	36	3,638.90	101.08	0.82
Levels of vision x distance	8	28,168.91	3,521.11	25.20*
Levels of vision x illumination	16	10,809.39	675.59	5.72*
Distance x illumination	8	6,643.00	830.38	5.37*
Subjects x level of vision x distance	72	10,058.31	139.70	1.14
Subjects x level of vision x illumination	144	17,005.16	118.09	0.96
Subjects x distance x illumination	72	11,133.30	154.63	1.26
Levels of vision x distance x illumination	32	7,402.72	231.34	1.89*
Subjects x level of vision x distance x illumination	288	35,304.73	122.59	
TOTAL	749	301,423.32		

*Significant beyond 1% level. **Significant beyond 5% level.

For the purposes of this study, the interactions of illumination and vision, and distance and vision, were of particular interest. In both analyses these interactions were highly significant, resulting in the conclusion that curves representing the relationship between vision and performance are a function of both distance and illumination. In other words, the trend of performance at different levels of vision is not the same under different levels of illumination. The same holds true for distance.

On the basis of these results it was concluded that performance curves developed under one set of conditions cannot be generalized to other conditions. In view of these conclusions performance curves representing the relationship between vision and performance were developed for both the time and accuracy scores for each set of conditions. Both free-hand and mathematical curves were developed for the time scores and free-hand curves only were developed for the accuracy scores. An illustration of the relationship between performance and vision at 5 levels of illumination at one distance is shown in Figure 8.

The curves for the first four illumination levels are based on the inverse function mathematical relationship. The curve for illumination level five (shown by a dotted line in Figure 8) was drawn by inspection because the inverse function did not adequately fit these data.

CONCLUSIONS

The following conclusions were drawn from the evidence obtained in this research:

1. The methodology evaluated in Phase III of the program of research provides a feasible means of establishing visual standards. Free-hand curves fitted to plots of vision

scores versus job-performance can be used to describe the relationship between vision and job-performance. Further, the problem of obtaining a range of vision for certain visual functions was solved by the use of clip-on crossed-cylinder lenses.

2. On the basis of the evidence obtained in Phase III, only very limited generalization of results from one visual task to another visual task can be made, because the trend of performance on different visual tasks was not the same at different levels of vision.

3. On the basis of the evidence obtained in Phase IV, results obtained under a given set of conditions cannot be generalized to other conditions because the trend of performance was not the same at different levels of vision for different conditions of illumination and distance from the visual task.

4. Although not within the realm of this study, the results appear to have implications for equipment design. The results of Phase III clearly indicate that certain types of dials are read faster and more accurately at all levels of visual acuity than other types of dials. These results warrant the conclusion that operators with poorer visual acuity could perform at a given level of proficiency on certain dials as well as, or better than, operators with better acuity could perform on other types of dials.

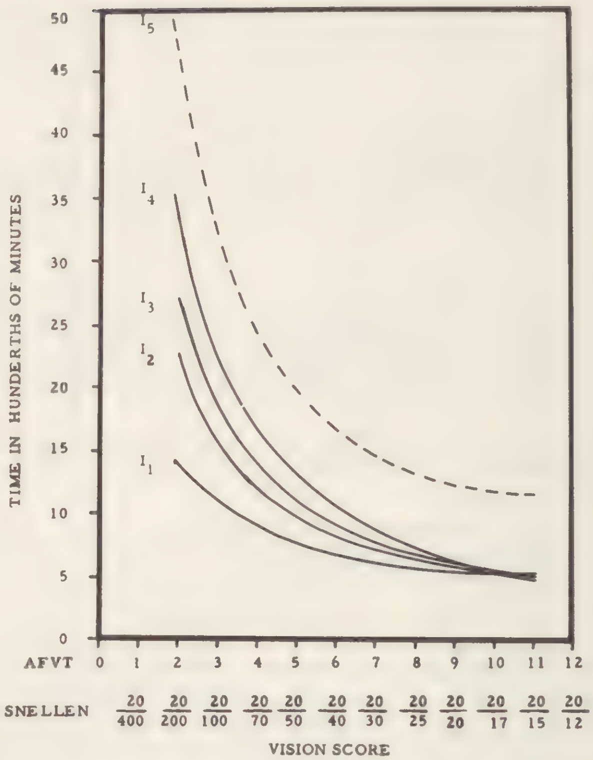

Figure 8. Relationship Between Near Visual Acuity and Time Performance on Dial Reading Task at Five Levels of Illumination Holding Distance Constant.

5. Also outside the realm of this research but of considerable interest are the implications of the results for selection and placement of personnel. Results of the dial reading tasks used in Phase III and Phase IV of the research, indicated that with every increment in near-visual acuity above the so-called normal, or 20/20, (Armed Forces Vision Tester Score of 9), level of acuity, the efficiency of performance was increased. This leads to the conclusion that the efficiency of performance on highly critical tasks might be improved by rigid visual requirements for those jobs. However, further research is recommended concerning this possibility before a definite conclusion is made.

The following procedure is recommended as a guide for application of the methodology developed:

1. The critical visual tasks for each battlestation assignment be identified.
2. Acceptable standards of performance for the identified visual tasks be agreed upon.
3. The level of illumination under which the task is performed be agreed upon.
4. The working distance from the dial be agreed upon.
5. The relationship between different visual functions and job performance be established by the following steps:
   a) Select approximately ten naval personnel experienced on the visual task being studied.

b) Have each man perform the visual task at least ten times, at each of five levels of vision.
   (1) The five levels of vision should be obtained using five sets of clip-on crossed-cylinder oblique lenses, varying from plano to four diopters between the power of the crossed-cylinders.

6. Plot performance against near acuity score on the Armed Forces Vision Tester.
7. Draw a free-hand curve showing the relationship between vision and job performance.
8. Locate the minimum standard of performance agreed upon in Step B on the obtained curve, the visual score below that point being the visual standard for that task.

In the above procedure steps 2, 3 and 4 must be resolved at the policy-making level. However, the remaining steps in the procedure can be performed by technicians under the direction of a research specialist. It appears reasonable to assume the amount of training required for the technicians would not be prohibitive; that a short intensive period of training would suffice.

THE PSYCHOMETRIC METHOD APPLIED TO VISION RESEARCH*

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Lately, researchers in vision have come to apply psychometric methodology more and more in the construction of acuity and other visual tests. This is a development in which the Armed Forces-NRC Vision Committee and the Personnel Research Branch of the Adjutant General's Office both played a part. It is the purpose of this paper to describe something of the circumstances leading to the application of these methods to visual research, and to describe some of the methodological problems which have lately been dealt with, particularly in our laboratory.

Psychometric methods may be defined as those concerned with "human ability measurement." In practice, they involve the group of statistical and test construction methods useful in measuring human abilities. It will be recognized that the emphasis of these methods differs somewhat from that of classical experimental psychology. In experimentation, the interest is primarily on the effect of a single or more independent variables on a dependent variable. The description is in terms of mean performance of an individual or a group. Differences among individuals are regarded as variability, limiting the generality of the findings. In applying psychometric methods, interest is not particularly on average performance; rather, it is strongly centered on individual differences. The aim is to provide a useful description of some human difference considered to be of importance, either of itself, or as a representative of a larger class of human behavior. Thus, the experimental psychologist is interested in the problem of the effect of illumination on visual acuity. The measurement research psychologist is interested in measuring visual acuity, and in assessing the importance of individual differences in acuity for predicting a criterion such as factory or battle field performance.

The application of psychometric methods to vision tests is a rather recent development. During World War II, it became evident that the methods of testing visual acuity used by the branches of the Armed Services gave inconsistent measures. At the 11th meeting of the Armed Forces Vision Committee, in 1945, the problems involved in developing an improved procedure were considered and a Subcommittee on Visual Examinations was formed. In its work in evaluating tests, this committee gave implicit recognition to the psychometric measurement approach. It had become clear that a vision test is a test, and that the principles applicable to test construction in general are applicable to vision tests in particular.

Let us now examine some of the basic steps of the psychometric approach. For convenience, the steps involved in this method have been categorized under 4 headings (3):

1. Development of test items. An experimental test is constructed, consisting of all items thought to be relevant. Information for this preliminary test may be gathered by consultation with experienced workers, through job analyses, or by observation of the men at work. The techniques of factor analysis are also helpful for this purpose.

*The contents of this paper reflect the opinions of the authors and do not necessarily represent the viewpoint of the Department of the Army.

2. Selection of test items. The experimental test contains many more items than will finally be used. This test is pruned to the proper length by retaining the most valid items and those in the difficulty level where discrimination is required.

3. Determining the characteristics of the completed test. The reliability, and more importantly, the validity of the completed instrument are determined. The validity of the test should be checked (cross validated) on a group different from that on which the final selection of items was based.

4. Standardizing the instrument. The scale of the test is calibrated, in reference to the population on which it will be used, in terms of percentile scores or standard deviation units. In vision tests, we may use Snellen scores, visual angles, decimal notation, or some other such metric.

In applying these steps, visual acuity test results have been expressed as number of items correctly answered. The use of numerical scores, in place of the usual Snellen notation, makes convenient a conventional statistical treatment of the data in terms of means, variances, coefficients of correlation, and so forth.

To illustrate in greater detail the four steps, we will now consider some methodological problems to which they have been applied:

A. The Development of Target Designs (these are the items of acuity tests).

An important problem in the development of acuity designs is that of identifying the abilities to be measured. For the preliminary charting of day or night acuity abilities, the methods of factor analysis which aim at reducing a large number of variables to the fewest possible underlying variables, are particularly applicable.

As has previously been reported to this Committee, a factor analysis of day visual acuity tests was carried out by the Personnel Research Branch of the Adjutant General's Office, in 1946 (8). The main finding of this study was that four abilities (in the factor analysis sense) explained the variance of the visual acuity tests analyzed. These were identified as:

1. Retinal resolution.
2. Brightness discrimination.
3. Form (letter) perception.
4. Simple form perception.

Although these four factors could be distinguished in the 17 acuity tests, the greatest variance of commonly employed visual acuity targets was that of retinal resolution. This factor analysis enabled us to narrow the possible kinds of visual acuity targets to the 2 or 3 most promising, namely—checkerboards, letters and rings.

In order to clarify the nature of night vision ability, a factor analysis of scotopic and mesopic tests is being conducted in our laboratory. Three night vision factors were tentatively identified, of which the two most important were: scotopic resolution and scotopic contrast. Some additional factors which explained part of the remaining variance have also been identified. A discussion of these secondary factors is not pertinent at this time.

B. The Selection of Test Items

A test may be revised on the basis of item analyses so that it is psychometrically an improved measure. Improved distribution and better discrimination may be obtained by adding items of difficulty levels between pile ups of scores.

The problem of selecting "best" items from many items is particularly critical in letter type targets. The task of selecting letters equal in difficulty has proven a knotty one. Letters have been found, invariably, to differ in legibility among themselves (1, 2, 5, 10).

An analysis has been carried out of letter difficulty on the failure line of the Sloan plates, and on the failure line of the Armed Forces Far Visual Acuity Test (7). These tests have the same 10 letters. The per cent correct response per letter on the failure line is a very relevant one for evaluating item difficulty.

It was found that the letter S, the most difficult of the 10 used, showed 2-1/2 times as many errors as the letter H, the least difficult letter. The range of difficulty was smaller than that found in previous studies, where letters above the failure line were analyzed.

Apparently, differences in letter difficulty are not as great as had formerly been concluded from studies not limited to the failure line. Line scoring methods, presently used in Army tests, would further vitiate differences in letter difficulty; although such scoring methods reduce the discrimination power of the scale. For conventional psychometric statistical analysis, such a limited range of scores is extremely inconvenient.

C. Determining the Characteristics of the Completed Test

As psychometric measures, acuity tests may be evaluated in respect to reliability and in respect to validity. The reliability of the test is an indication of the reproducibility of the test measure. The validity, more importantly, indicates the amount of variance actually explained in reference to a relevant criterion. The correlation of an acuity test with other tests may also be considered. Such an index roughly indicates whether or not the tests measure the same ability.

A comparative analysis of nine visual acuity tests was carried out in a recent Personnel Research Branch Study (6).

Table 1

INTERCORRELATIONS OF VISUAL ACUITY TESTS. (N = 117)

Tests	1	2	3	4	5	6	7	8	9
1 Army Snellen	(.76)								
2 AF-Far Visual Acuity	.66	(.81)							
3 New Army Snellen	.72	.88	(.88)						
4 Bausch and Lomb Checkerboard	.69	.75	.74	(.79)					
5. Mod. Landolt Ring	.64	.67	.73	.67	(.75)				
6 Line Resolution	.49	.65	.71	.71	.64	(.90)			
7 Ortho-Rater Sloan Binocular	.60	.77	.72	.70	.75	.65	(.83)		
8 Ortho-Rater New Army Snellen	.67	.87	.89	.77	.73	.79	.84	(.92)	
9 Ortho-Rater Mod. Landolt Ring	.60	.69	.72	.70	.79	.78	.75	.78	(.85)

The two-week test-retest reliabilities are given in parentheses on the diagonals. The intercorrelations are represented by the other entries of the matrix.

The new Army Snellen may be signaled out for special attention. This test shows a two-week test-retest reliability of .88 as a wall chart, and of .92 as an Ortho-Rater plate. The two-week test-retest reliability of the original Army test from which it was revised was .76. The new test was revised from the older chart by adding sizes where pile-ups of the original distribution indicated insufficient discrimination. On the basis of these results, the New Army Snellen Test appears to have quite excellent psychometric qualities.

Much less work has been done on the validity of visual acuity tests than on their reliability. This is because of the difficulty, in most cases, of constructing adequate criteria. In industrial studies, tests have been related to output records (12), earnings (13), and accident rates (11). Some effort has also been made in military research to relate acuity scores to ratings of battle performance (9). These validity studies represent fruitful lines of research answering the practical question: "What does a visual acuity score indicate in terms of predicting meaningful performance?"

D. Standardizing the Instrument or Test

Visual tests may be standardized as wall charts, or for use in instruments with optical simulation of distance. Instruments may be recommended because of their intrinsic control of lighting and distance, and because they require relatively little space. However, it may be questioned that a score obtained on an instrument is equivalent to that obtained on a wall chart. To examine this question, in one instance, a comparison was made of Armed Services Vision Tester and wall chart presentation (4). A letter chart and a modified Landolt ring chart were photographed on the instrument plates.

In establishing equivalences, in studies of this sort, a counterbalanced order is usually necessary. In determining the correlational characteristics, counterbalancing is not desirable.

It was found that the reliabilities of the Armed Services Vision Tester scores were significantly higher than those of the wall chart scores.

Table 2

WALL CHART AND ARMED SERVICES VISION TESTER TEST-RETEST RELIABILITIES. (N = 117)

	Letter Test			Landolt Test		
Scoring Method	Wall	Instrument	t-Ratio	Wall	Instrument	t-Ratio
A	.81	.90	3.30**	.73	.81	1.94
B	.78	.89	3.69**	.69	.79	2.14*
C	.88	.92	2.04*	.75	.85	2.82**
D	.80	.87	2.23*	.65	.79	2.91**

The reliabilities were computed by four methods:

A. Number of rights before two consecutive miscallings were first made.
B. Number of items attempted before two consecutive miscallings were first made.
C. Number of rights before three consecutive miscallings were first made.
D. Number of items attempted before three consecutive miscallings were made.

A single asterisk indicates a difference between the reliabilities significant at the 5% level; a double asterisk indicates a difference significant at the 1% level.

It may be seen that with a single exception, the instrument test scores are significantly more reliable than those of the wall chart tests. These results may possibly be explained by the relatively large black-white contrast of the refracted instrument plate as compared to that of the reflected chart.

An indication of the communality of visual abilities measured by wall charts and instrument plates is given by the correlations between scores.

Table 3

CORRELATIONS BETWEEN WALL CHART AND ARMED SERVICES VISION TESTER. (N = 117)

	W-C Test vs. Instrument Test	W-C Retest vs. Instrument Retest	W-C Retest vs. Instrument Test	W-C Test vs. Instrument Retest
Letter	.85 (.94)*	.87 (.97)	.86 (.96)	.89 (.99)
Landolt	.78 (.98)	.84 (1.00)	.77 (.96)	.80 (1.00)

*Correlations corrected for attenuation are given in parentheses.

The correlations in parentheses are corrected for attenuation due to unreliability of both the wall chart and the instrument test.

Apparently, wall charts and duplicate instrument plates measure the same visual abilities. The correlations are about as high as the test-retest reliabilities. The mean of the corrected correlations is .98, close to unity. For practical purposes, the instrument test may be substituted for the wall chart test.

In this paper, a brief discussion has been given of the psychometric methods used in the development of tests and of some of the problems considered in applying these methods to acuity test construction. It may be hoped that psychometric methods will find further application, supplementary to the techniques of classical experimentation, in the solution of problems for which they are peculiarly adapted.

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REPORT ON THE EVALUATION OF THE FREEMAN ILLUMINANT-STABLE COLOR VISION TEST

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At the April meeting of the Vision Committee I outlined our proposed plan for evaluating Freeman's Color Vision Test. As you perhaps remember, the plan consisted of three parts: Part I--an evaluation of the test's illuminant-stability, Part II--an evaluation of its reliability, and Part III--an evaluation of its validity. At this time I will present the results of Parts I and III. Test-retests for Part II were interrupted when the laboratory was moved last summer and will have to be repeated later.

First, a brief description of Freeman's Color Vision Test. It is a loose-leaf book consisting of six colored plates with the following numbers on them--5, 3, 6, 8, 97, and 2. On the inside cover is a page devoted to instructions and explanation. The paragraph entitled "Administration" includes the following information: the plates are to be presented for about 5 seconds each at 35 to 50 cm. from the eyes and roughly perpendicular to the line of regard. And, of course, it is pointed out that the test "works under whatever illumination is available." The paragraph entitled "Diagnosis" reads "Since normals read all the plates and color-blind virtually none, diagnosis is clear. However, the normal may be forgiven one miss, to allow for the rare case where an extraneous factor, like severe refractive errors or inferior intelligence, introduce mere reading difficulty."

The Medical Research Laboratory Test Battery was used to classify the subjects as normals or color defectives and to classify the color defectives as to type (protan or deutan) and degree of defect (mild, moderate, or severe). The battery consisted of the American Optical Company Plates, 2nd Edition, Revised (our MRL design) and the Hand Anomaloscope (these two tests agreed in all cases in dichotomizing color defectives from normals); the Navy Lantern; and the Dichotomous-15 Test. One hundred normals and twenty-five color defectives were used, and each subject was tested on the Freeman charts under three commonly-available illuminants--daylight, i.e., "C", room incandescent, i.e., a warm "A" (2650^{O}K), and fluorescent "white" (of an intermediate color temperature of about 3600^{O}K)--at two-week intervals for normals and at intervals ranging from months to not less than one day for color defectives. The order of presentation of the three illuminants was organized in a Latin Square Design, and each of the six groups contained an approximately equal number of normals and of mild, moderate, and severe deutans and protans. The test was administered in accordance with Freeman's directions, the plates in regular, random, and reverse order. Two or more errors classified a subject as color defective.

Now to the results. How valid was the Freeman test for normals and was the classification consistent under the three illuminants? Of the 100 normals tested, 90% were correctly classified regardless of which illuminant was used. This leaves 10% who were misclassified by the Freeman Test under incandescent or fluorescent: no one was misclassified by Illuminant "C", 5 normals misclassified by incandescent, and 5 others misclassified by fluorescent. It appears therefore that the validity of the Freeman Test when given as directed (i.e., "under whatever illumination is available") is not as high as the validity of the presently-used American Optical Company Plates when given as directed (i.e., "under Macbeth Daylight lamp or its equivalent or by diffused daylight which consists largely of skylight") in view of the fact that 90% of the normals passed the Freeman Test whereas 100% passed the A.O.'s. Under Illuminant "C", the Freeman Test is also 100% valid, but then the chief advantage claimed for it--namely, its illuminant-stability--is lost.

How valid was the Freeman Test for color defectives and was the classification consistent under the three illuminants? Of the twenty-five color defectives tested, 80% were correctly classified regardless of which illuminant was used. This leaves 20% who were misclassified by the Freeman Test: of the 25 color defectives, 5 were misclassified under some illuminant--2 were misclassified by Illuminant "C", 2 others misclassified by incandescent, and 1 other misclassified by fluorescent. It appears therefore that the validity of the Freeman Test when given as directed is not as high as the validity of the presently-used American Optical Company Plates, which all of the twenty-five color defectives failed. The data shows that the Freeman Test is not valid for mild and moderate defectives when used under "any" illuminant. It is 100% valid--under any of the three illuminants--for severe color defectives only.

In summary, our data shows that the Freeman Test is valid for normals under Illuminant "C" and is valid for severe deutans and protans under Ill. "C", incandescent, and fluorescent. It is not valid for normals under illuminants other than "C" and it is not valid for mild and moderate color defectives under any illuminant.

FURTHER ANALYSIS

1. It was found that 9 out of the 10 normals who failed the Freeman Test did so the first time they took the test but passed it on their second and third trials (under different illuminants). The five color defectives who passed the Freeman Test did so on the second and third trials after failing on the first trial. Hence we can not suggest that if a subject fails the plates he be retested because although it would then increase the test's validity for normals under any illuminant, it would decrease the validity for color defectives. If we used first tests alone, misclassification would result for normals; if we used retests alone, misclassification would result for color defectives.

2. The plate which caused normals the most difficulty was "8"; this was administered all told 300 times to the 100 normals and was failed 52 of those 300 times. To increase the validity of the test for normals we cannot suggest elimination of this plate since if we did so the validity of the test for color defectives would be further decreased. The data shows that elimination of "8" would increase the validity of the test for normals from 90% to 95% but would decrease the validity of the test for color defectives from 80% to 65%.

3. Severe protans easily learn to read the first three plates on the basis of brightness differences.

4. A plate for malingerers is not included in the test.

5. The instructions failed to say "read aloud the number on each card." It was found that some of the normals who appeared to be failing all six plates were doing so because they were reading the numbers to themselves (silently). Normals who are not saying anything aloud can readily be confused with color defectives who are not seeing anything.

6. The test is so short it is easily memorized and therefore would be unusable by the Navy. The data from the first 77 subjects had to be discarded because it was impossible to prevent communication between service men in an ordinary naval situation--and this was found to affect their scores.

RESEARCH RESULTS IN ATMOSPHERIC OPTICS

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1. New Computations of the Mie Scattering Functions

The way light is scattered in the atmosphere has become of increasing interest to meteorological research. One of the important factors is a sound knowledge of the scattering characteristics of particles, the size of which is comparable to the wavelengths of the incident light.

This problem was solved theoretically over forty-five years ago by G. Mie. His formulae are exact solutions of Maxwell's equations for spherical particles of any size and material. He integrated Maxwell's equations for the field inside and outside the particles and calculated the amplitudes of the waves of light radiated by the particle in various directions. The exact solutions appear in the form of series which converge more slowly the larger the radius of the particle for a fixed wavelength of incident light.

Various investigators have since used his formulae to carry out numerical computations. Unfortunately, this becomes an extremely time-consuming task for large radii, because many terms of the series have to be computed, and therefore some of the earlier computations are unreliable for large radii. Thus, the available data are limited.

The only reliable results for large radii are published by Gumprecht; however, he used very large increments of the size parameter. The existing tables do not meet the need we have for such tables. Therefore, we planned new computations with three objectives in mind, namely, computations for:

(1) refractive indices of atmospheric particles and particles used in our laboratory work,

(2) small steps of radii up to particle sizes which occur in the atmosphere,

(3) small steps in angular direction to determine the angular distribution more accurately.

Since new high-speed electronic computers exist, the IBM 701 electronic data processing machine was selected as best suited for this purpose.

The results obtained will be presented in several volumes, each one containing the total scattering coefficient K and the two angular scattering functions i_1 and i_2 for a particular value of the refractive index m. To give an idea of the scope, 1500 values of the total scattering coefficient and 99,200 values of the angular scattering function have been computed and will be published. The total Mie scattering coefficients have been computed for $0 \leq \alpha \leq 30.0$ in steps of $\Delta\alpha = 0.1$, for indices of refraction m = 1.33, 1.40, 1.44, 1.486 and 1.50. The angular distribution functions have been computed in steps of 5° between $0^{\circ} \leq \gamma \leq 170^{\circ}$ and in steps of 1° between 170° and 180°. The values are computed for 10 digits, but because of the iteration procedure, only five digits are correct for the largest values of the size parameter.

Two examples are shown for the total scattering coefficient K, namely, m = 1.33 and m = 1.486. The curves show a lot of detail which is correct. Smoothed curves have been computed which will satisfy most of the practical problems. They are far superior to older data because the curves are known with all details.

The scattering functions also show a lot of detail and the small angular steps taken were justified.

It is planned to compute mean values for atmospheric particle size distributions, so that the theoretical data can be compared with experimental results.

2. Cloud Visibility

The coefficient C in Trabert's visibility equation, $V = (C\rho\bar{r})/W$, where $\bar{r}$ is linear mean radius, ρ density, and W is liquid-water content, is shown to be a function of the breadth of the drop-size distribution but has preferred values in natural clouds ranging from 3.3 for fair-weather cumulus to 4.8 for nimbostratus. The frequently quoted value of

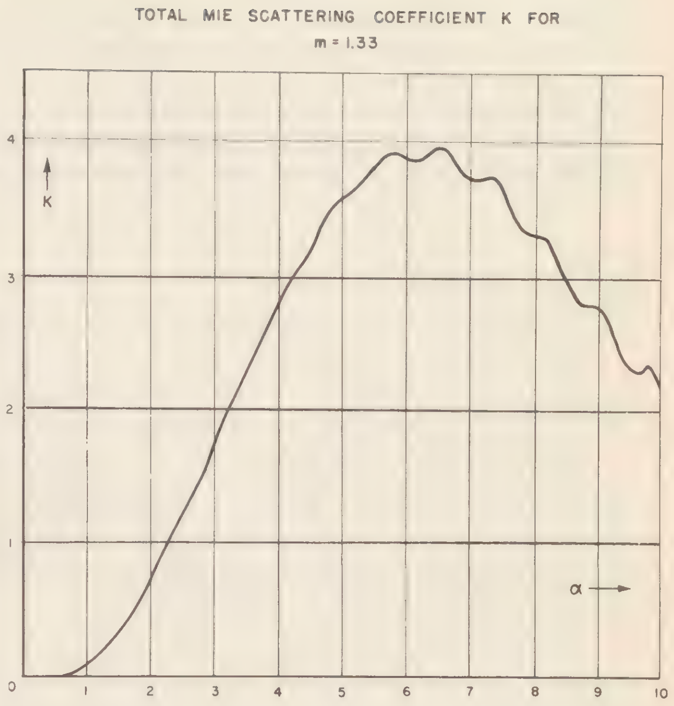

Figure 1a.

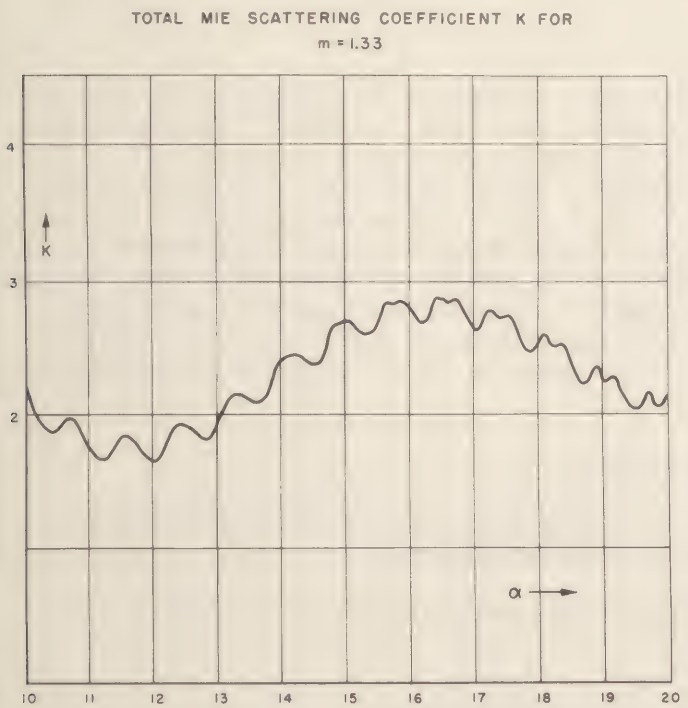

Figure 1b.

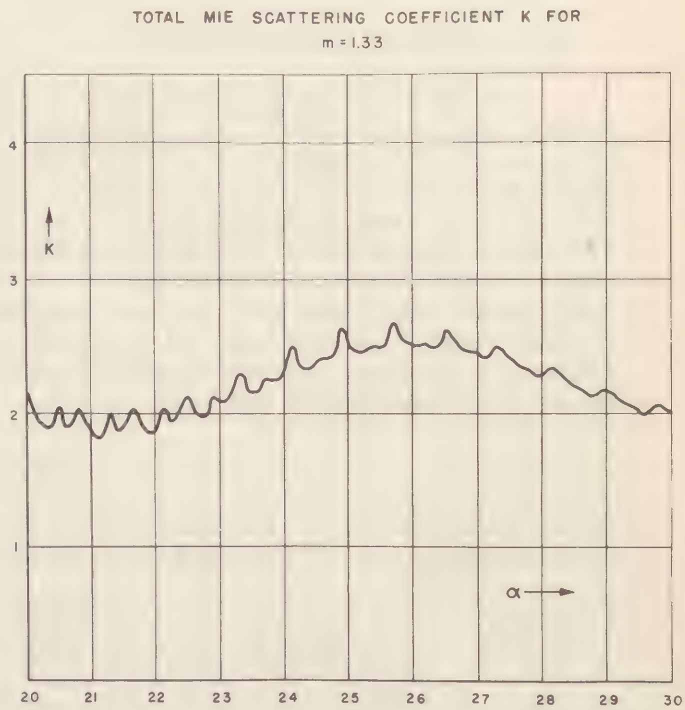

Figure 1c.

2.6 pertains only to a perfectly monodisperse distribution, and is inappropriate in nature. A more useful equation is found to be $V = (K\rho d_o)/W$, in which d_o is the median volume diameter and the coefficient K is found to be very nearly independent of the breadth of the drop-size spectrum over the range which occurs in natural clouds. K = 1.2 is shown to be an excellent value for 65 observations by Diem. Similarly, the coefficient G in the radar-reflectivity equation, $Z = (6/\pi)Gd_o^3(W/\rho) \times 10^{-6}$ has a preferred value of 1.35. The implication is that nature has a preference for a particular type of drop-size spectrum.

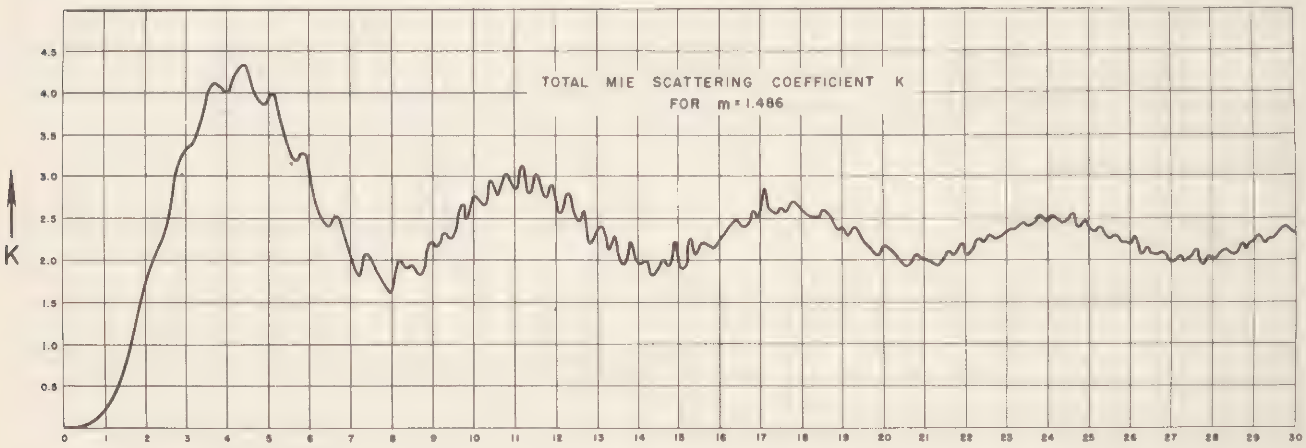

Figure 2.

3. Optical Extinction by Rainfall

The optical extinction coefficient σ due to rain is found to be related to the rain intensity R by $\sigma = 0.25R^{0.63}$ in Bergeron type rainfall and by $\sigma = 1.25R^{0.33}$ in drizzle and warm orographic rainfall. If the threshold of contrast is taken as 0.055, and rain is the only significant obstruction to visibility, the daytime visual range may be estimated from $V \simeq 11.6R^{-0.63}$(km) in Bergeron type rain and $V \simeq 2.4R^{-0.33}$ in warm orographic rainfall. The coefficient in the σ - R relationship appears to be fairly sensitive to variations in the nature of the drop-size distribution; particularly to the spatial concentration. Provided that other scattering media such as haze and dust can be accounted for, optical transmission measurements in rainfall should be helpful in characterizing its spectrum and possibly its origin. Such measurements should, therefore, be useful in adjusting the proportionality factor in radar-rainfall observations.

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Discussion:

Mr. Middleton asked if the figures on the Mie theory had been published anywhere.

Dr. Penndorf replied that these figures will be published in several volumes in the near future. About 20,000 scattering functions have been tabulated and will be printed just as they came out of the IBM machine—which means that the last five digits should be disregarded.

THE EFFECT OF TEMPERATURE, MOISTURE CONTENT, AND CLOUDS ON ATMOSPHERIC BRIGHTNESS

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INTRODUCTION

The problem of determining the "visual range," or that distance at which a particular object may be just distinguished from its background, has been receiving increasing attention since it was first systematically attacked by Koschmieder in 1924. In the case of ground-to-air or air-to-air detection, the background is the sky and the determination of the visual range for any given set of conditions must necessarily involve the specification of the luminance, or brightness, of that portion of the sky in close proximity to the target. Many measurements of sky brightness have been made by various observers and certain general relationships between sky brightness and such physical variables as altitude of the observer, zenith angle of the point under observation, bearing of the observed point from the sun, etc., have been ascertained. In other words, it has been possible to obtain, in a general way, a geometrical solution to the problem of sky brightness for use in making predictions of the brightness of related portions of the sky when the brightness of a single point is known. To date, however, the general effort has been to attempt to specify these relationships under conditions where the meteorological variables are held relatively constant. This has been necessary in order to determine the basic nature of the brightness relationships. It has, however, had the effect of limiting the generality of the findings to those instances when there is no cloud contamination of the sky.

PURPOSE

It is the purpose of this paper to report findings derived from data gathered under cloud conditions (2). Data was gathered on five days when heavy cloud conditions prevailed. As a rule, no data were gathered unless there was an overcast ranging from seven-tenths clouds to complete overcast.

INSTRUMENTATION

The equipment used in this study is illustrated in Figure 1. It is composed essentially of electronic photometers, a selector switching unit, an amplifier, an indicating meter graduated in light units, and an oscillograph recorder. The light sensitive unit of the photometer is a 931A photomultiplier tube especially selected for sensitivity, dark current response and color response. The tube is housed in a light-proof box along with its associated resistors. In front of the sensitive surface of this phototube is an 8.5 power telescopic lens system that projects the image of the area of view upon the sensitive surface of the tube. A circular stop is placed between the lenses at their common focal point to limit the field of view to 20 minutes of arc. A Wratten No. 101 filter is placed in the optical system to absorb light of wave lengths shorter than 400 millimicrons. This filter when combined with the selected photomultiplier tube gives the system a sensitivity that closely approximates the sensitivity of the human eye.

The signal generated by the photometer is passed through a motor-operated selector switch which permits the operation of three photometers on the same amplifier. The amplifier suppies the voltage to the photomultiplier tube and makes available a logarithmic

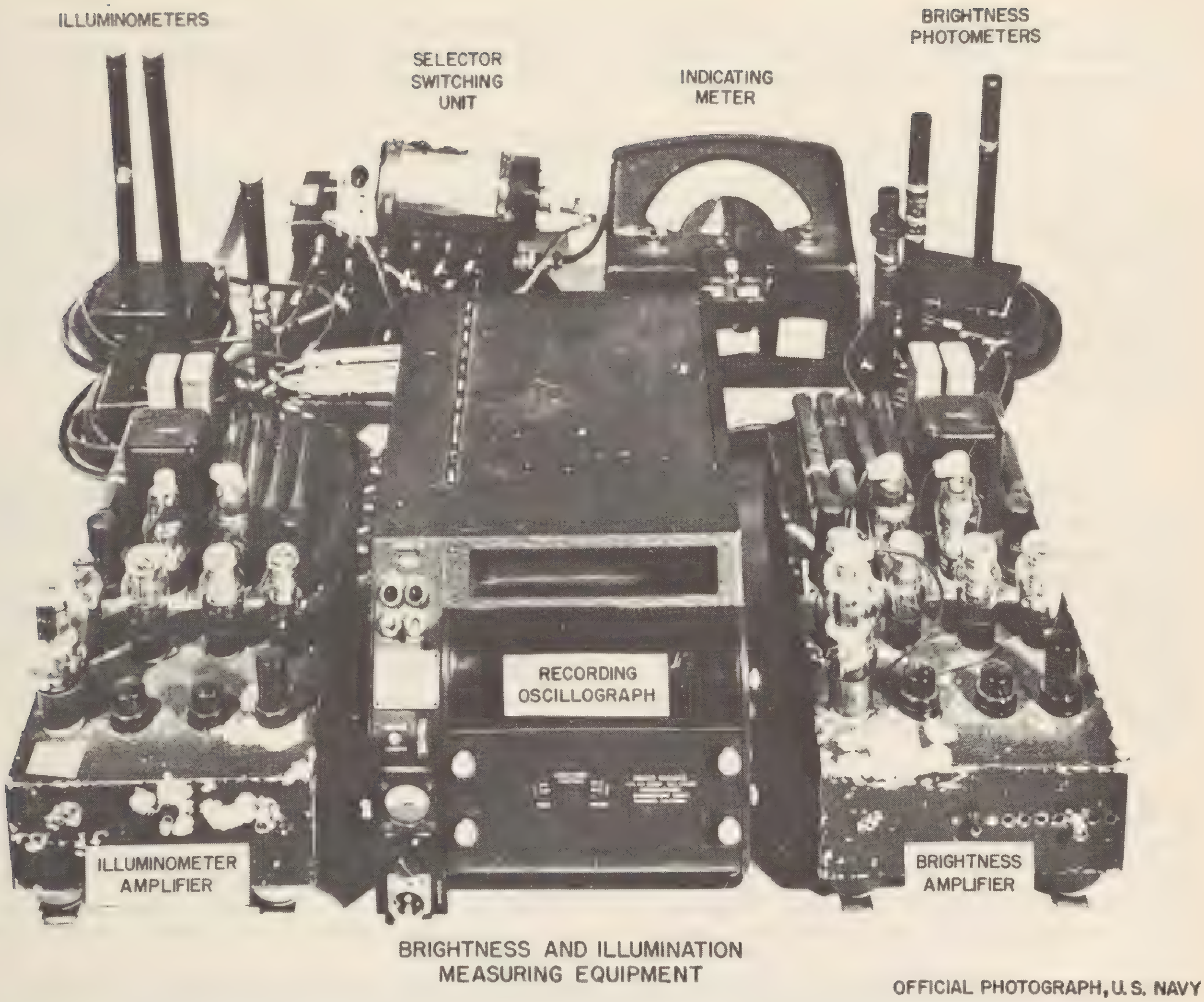

Figure 1.

amplification of the signal with a sensitivity range of four log cycles. One hundred and seventeen volt, four hundred cycle power is supplied by an inverter operating from the 28-volt aircraft supply.

The indicating meter is a Weston Model No. 273 voltmeter which has been modified to respond through a range of four log cycles when operated with the amplifier, and which is provided with a four log cycle scale.

The recorder is a Consolidated Engineering Corporation 18-channel oscillograph recorder, Model No. 5-114. The linearity of the galvanometers used with the recorders in this study corresponds closely with that of the indicating meter.

The photometers were calibrated in foot-lamberts. A sensitivity range of 10 to 100,000 foot-lamberts was used. A calibration lamp with a flat, flash opal diffusing surface and a blue filter which gives the lamp a color temperature approximating that of the sky, provided a means of brightness comparison between the Macbeth illuminometer and the photometers. The brightness of the opal glass diffusing surface was measured with the Macbeth illuminometer, the blue filter being removed to avoid a color disparity. The brightness reading was multiplied by the integrated transmission of the blue filter to obtain the brightness remaining after the blue filter was replaced. The circuit was calibrated by actuating the photometer

with the calibration lamp and adjusting the iris diaphragm of the photometer telescope until the indicating meter registered the known brightness of the calibration lamp. The recorder was calibrated to track with the calibration meter over each of the four log cycles.

METHOD

Data were collected at certain pre-selected altitudes ranging to 35,400 feet and 50,000 feet in some instances. An R4D aircraft collected all data below 15,000 feet and an F2H jet aircraft, operating simultaneously, was used for the higher altitudes. On the majority of the days, a total of eleven altitudes were flown. The photometers were positioned so that brightness measurements were made of the zenith and the nadir and circumferentially through 360 degrees at zenith angles of 30, 70, 85, 110, and 150 degrees, while the airplane made one 360-degree turn to the left and another to the right.

RESULTS

Figure 2 presents the pseudo-adiabatic diagram for 11 September 1951. This diagram shows the U.S. Standard atmospheric pressure-temperature relationship, and recordings of both temperature and dew point as a function of altitude and pressure. The diagram shows that for this particular day, the temperature lapse rate was tending toward a wet lapse rate and the dew point was in close proximity to the temperature to a pressure of approximately 700 millibars, beginning to diverge from that level upward. Whenever the dew point and temperature approximate each other for a range of altitudes, conditions are favorable for the formation of a fairly deep cloud layer. On this day, an almost complete overcast did exist, with tops at approximately 11,400 feet.

The pseudo-adiabatic diagram for 30 August 1951 is presented in Figure 3. This shows the presence of a definite low altitude temperature inversion. The lapse rate of the dew point line is less toward the wet side than was that on 11 September 1951. The fact that the dew point and temperature lines do come into close proximity at one point, however, indicates the presence of some clouds. The cloud coverage was considerably less than three-tenths on this day, however, hence the day could be classed as a clear weather day.

Dust and other large particles in the atmosphere tend to settle through a temperature inversion and are trapped below it. Convection currents below the level of the inversion mix these particles more or less uniformly throughout the air mass so that the number per unit mass of atmosphere is fairly constant below the inversion. The size of these particles, on the other hand, varies with the relative humidity. Near the surface where the temperature and dew point are widely separated, the particles are relatively small. As they are carried upward by convection currents, the air cools adiabatically, the temperature and dew point approach each other, and the particles take on water and increase in size. This increase in particle size is accompanied by an increase in atmospheric brightness and atmospheric attenuation. The effect of this change in particle size is demonstrated in Figures 4, 5, 6, and 7 which present data gathered on 30 August 1951.

Curves based on data gathered at a zenith angle of 85 degrees are seen to start below the theoretical curve and rise as the plane ascends to the level of the temperature inversion. At low altitudes, the path of sight of the 85-degree photometer in general is parallel to the plane of the temperature inversion; consequently, the larger particles come into the field of view at a great distance, thus allowing attenuation to reduce the effective brightness. At higher levels, this photometer is pointing through increasing numbers of these large particles and is closer to them and the brightness rises.

Data gathered at a zenith angle of thirty degrees, on the other hand, start in value higher than the theory curve and decrease as the plane ascends to the temperature inversion.

LATITUDE 53° 35' N.
LONGITUDE 113° 35' W.

TEMPERATURE — MOISTURE SOUNDING

DATE 11 SEPT. 1951
TIME 1500 Z

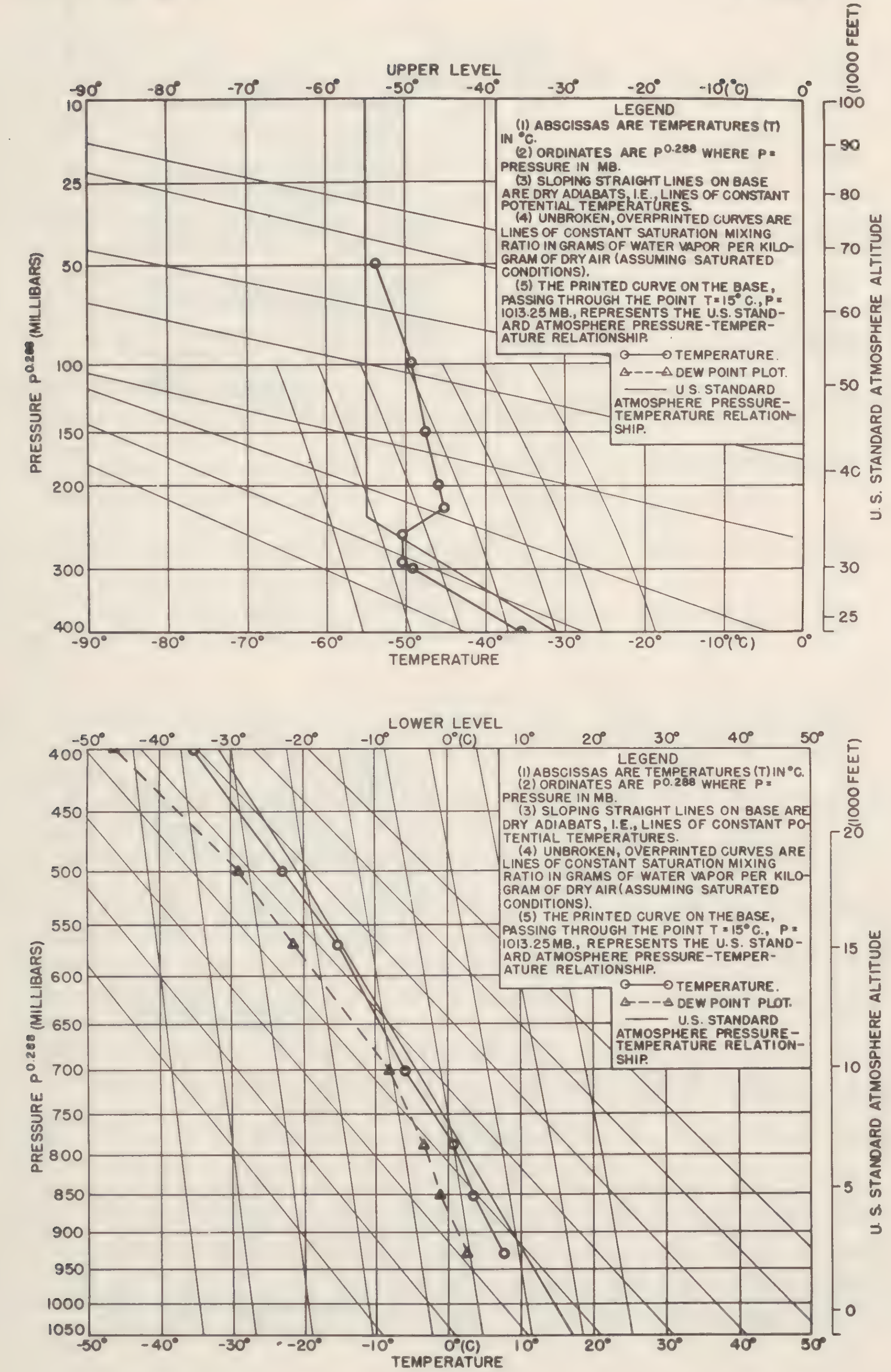

FIGURE 2

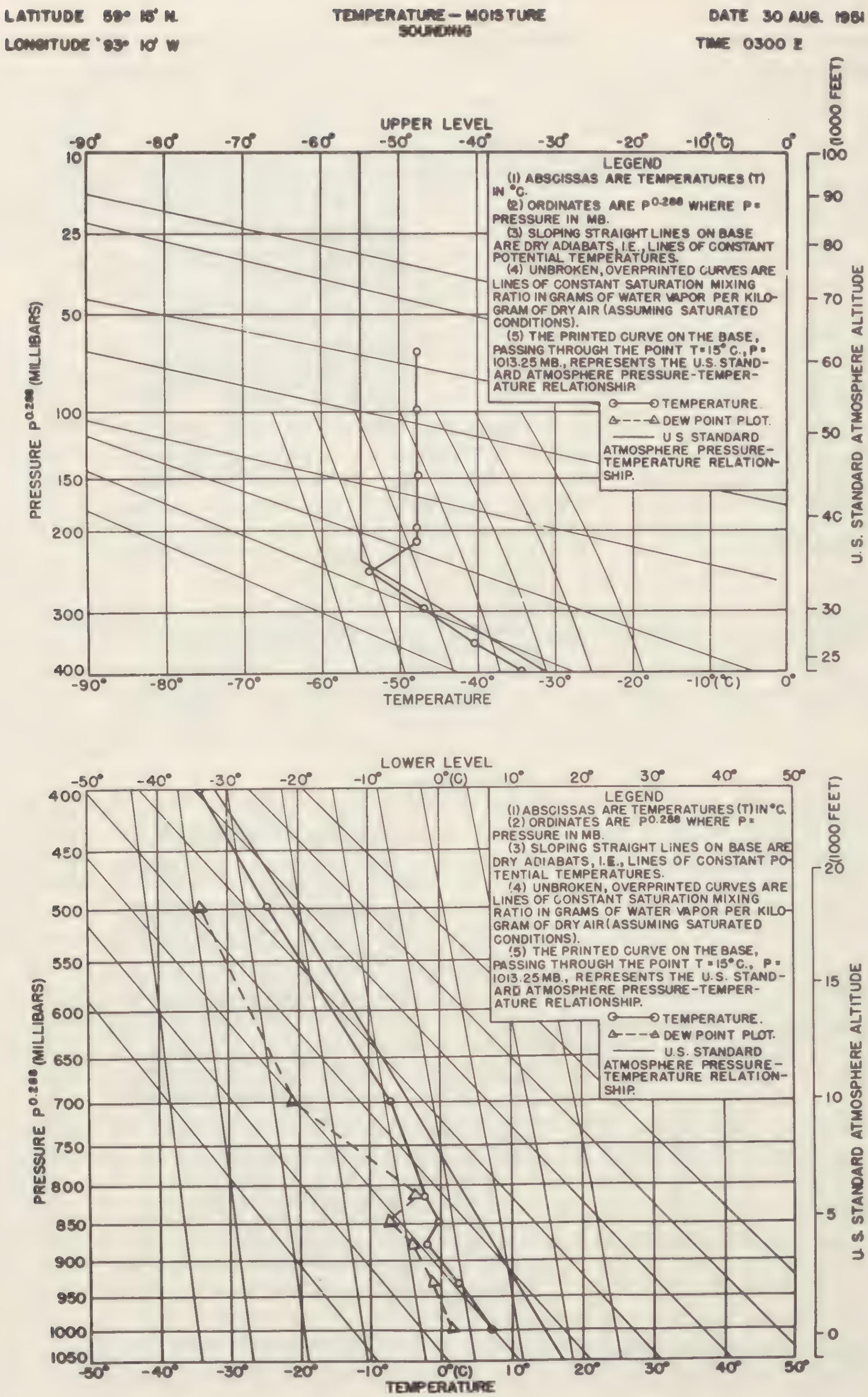
LATITUDE 59° 15' N.
LONGITUDE 93° 10' W
TEMPERATURE — MOISTURE SOUNDING
DATE 30 AUG. 1951
TIME 0300 Z
UPPER LEVEL
LEGEND
(1) ABSCISSAS ARE TEMPERATURES (T) IN °C.
(2) ORDINATES ARE P0.288 WHERE P= PRESSURE IN MB.
(3) SLOPING STRAIGHT LINES ON BASE ARE DRY ADIABATS, I.E., LINES OF CONSTANT POTENTIAL TEMPERATURES.
(4) UNBROKEN, OVERPRINTED CURVES ARE LINES OF CONSTANT SATURATION MIXING RATIO IN GRAMS OF WATER VAPOR PER KILOGRAM OF DRY AIR (ASSUMING SATURATED CONDITIONS).
(5) THE PRINTED CURVE ON THE BASE, PASSING THROUGH THE POINT T=15°C., P=1013.25 MB., REPRESENTS THE U.S. STANDARD ATMOSPHERE PRESSURE-TEMPERATURE RELATIONSHIP.
TEMPERATURE.
DEW POINT PLOT.
U.S. STANDARD ATMOSPHERE PRESSURE-TEMPERATURE RELATIONSHIP.
PRESSURE P0.288 (MILLIBARS)
U.S. STANDARD ATMOSPHERE ALTITUDE (1000 FEET)
TEMPERATURE
LOWER LEVEL
LEGEND
(1) ABSCISSAS ARE TEMPERATURES (T) IN °C.
(2) ORDINATES ARE P0.288 WHERE P= PRESSURE IN MB.
(3) SLOPING STRAIGHT LINES ON BASE ARE DRY ADIABATS, I.E., LINES OF CONSTANT POTENTIAL TEMPERATURES.
(4) UNBROKEN, OVERPRINTED CURVES ARE LINES OF CONSTANT SATURATION MIXING RATIO IN GRAMS OF WATER VAPOR PER KILOGRAM OF DRY AIR (ASSUMING SATURATED CONDITIONS).
(5) THE PRINTED CURVE ON THE BASE, PASSING THROUGH THE POINT T=15°C., P=1013.25 MB., REPRESENTS THE U.S. STANDARD ATMOSPHERE PRESSURE-TEMPERATURE RELATIONSHIP.
TEMPERATURE.
DEW POINT PLOT.
U.S. STANDARD ATMOSPHERE PRESSURE-TEMPERATURE RELATIONSHIP.
PRESSURE P0.288 (MILLIBARS)
U.S. STANDARD ATMOSPHERE ALTITUDE (1000 FEET)
TEMPERATURE

Figure 3.

The 30-degree photometer is pointing at all times directly into and is relatively close to the large-particle area. Consequently, the effective number of these brightness-producing particles decreases with the ascent of the plane.

The first demonstration of the effect of the cloud overcast is shown in Figure 4. Here are presented two plots showing the brightness of the sky at a zenith angle of 30 degrees and a bearing of 90 degrees as a function of pressure first for the clear day (30 August 1951) when virtually no clouds were present and then the cloudy weather day (11 September 1951) with its almost complete overcast. The dotted line in each plot is based on points computed from the Tousey-Hulburt theory of sky brightness (3). It will be noted that for the clear weather data, the 30-degree curve closely approximates the theory curve for all pressure levels. Under cloudy weather conditions, however, this curve is highly erratic but in general greatly exceeds the theoretical curve to the top of the cloud layer at about 700 millibars. From there upward the form of the curve becomes smooth and is the same as on a clear day. Figure 5 shows data taken at the same zenith angle but at a bearing from the sun of 180 degrees. The same relationships are seen to exist.

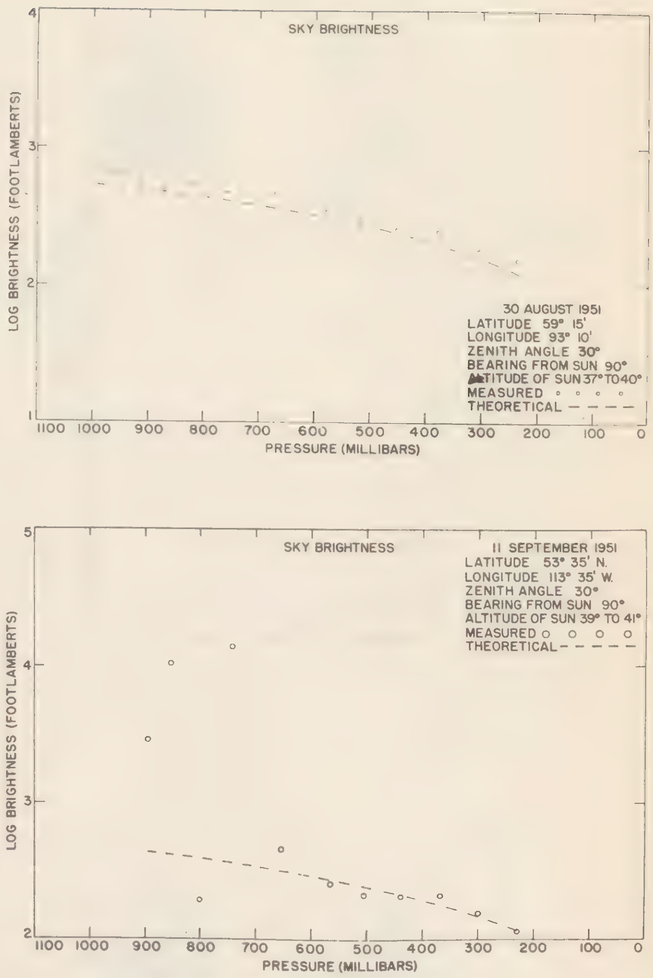

Figure 4.

Figure 6 consists of two plots based on data taken on the same two days. These plots show the brightness of the sky at a zenith angle of 85 degrees and a bearing from the sun of 90 degrees as a function of pressure. On the clear weather day (30 August 1951) it will be noted that the data points form a relatively flat curve, falling under the theoretical curve to approximately 600 millibars and exceeding it from there to 250 millibars. This curve constancy indicates that, at least for the altitudes reported and for points of observation near the horizon, the brightness of the sky is not proportional to the total length of the path of sight through the atmosphere. The data shown for the cloudy day indicate that sky brightness at an 85-degree zenith angle also exhibits considerable variability below the cloud overcast and is in opposition to the case of 30-degree zenith angle brightness in that it falls beneath the theoretical curve to a level of 600-700 millibars. From this level to 250 millibars, the data exceed the theoretical values and the curve is relatively flat just as was the case under clear weather conditions. Figure 7 shows data taken at the same zenith angle but at a bearing from the sun of 180 degrees. Again, the same relationships are seen to exist.

The general relationship between the brightness of the sky and the zenith angle of observation under both clear and cloudy weather conditions is summarized in Figure 8. These plots clearly demonstrate that at a low altitude, under the cloud overcast, the brightest portion of the sky is at or near the zenith. At a higher altitude, above the cloud layer, the brightness-zenith angle relationship is similar for both days and the usual clear weather picture is seen in which the brightest portion of the sky is at the horizon.

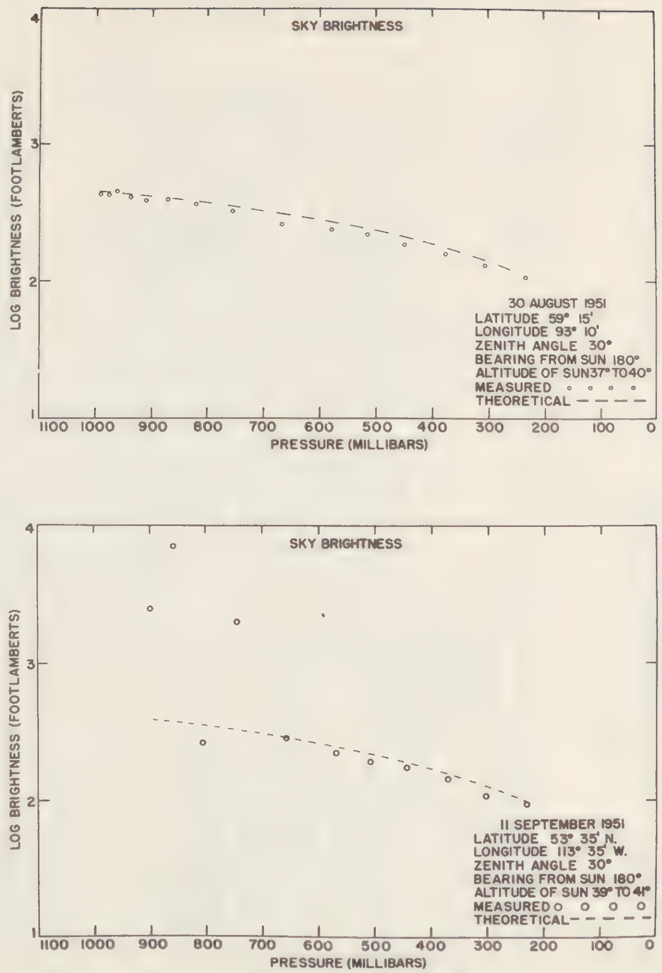

Figure 5.

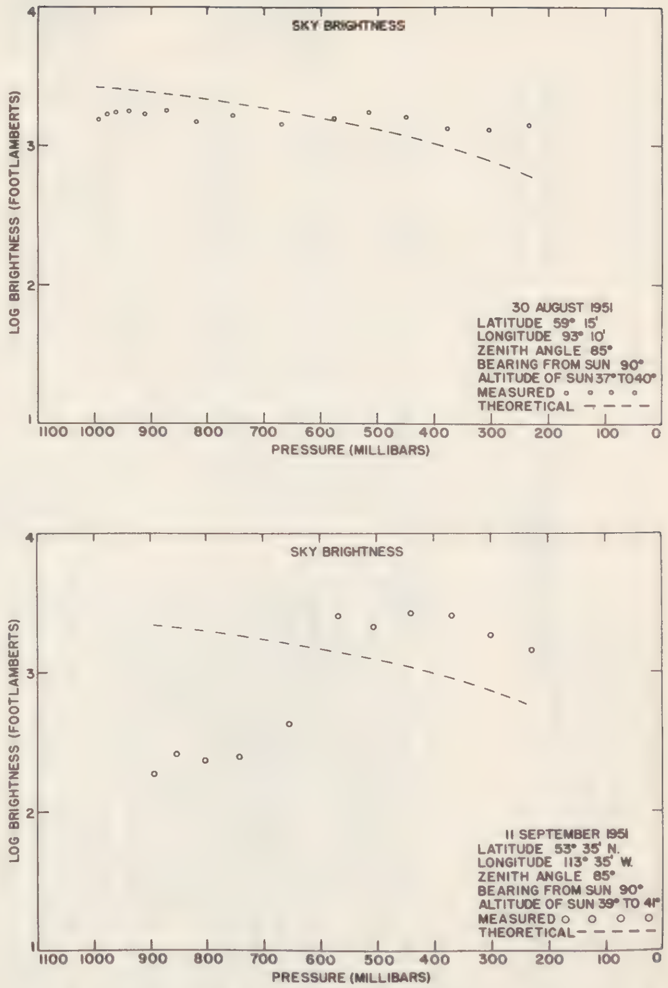

Figure 6.

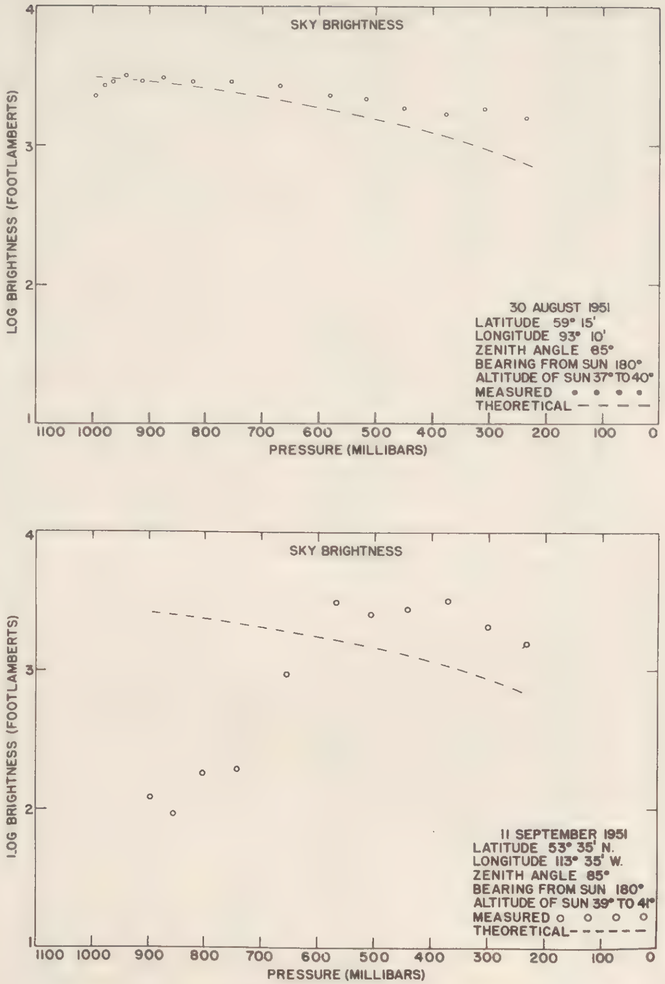

Figure 7.

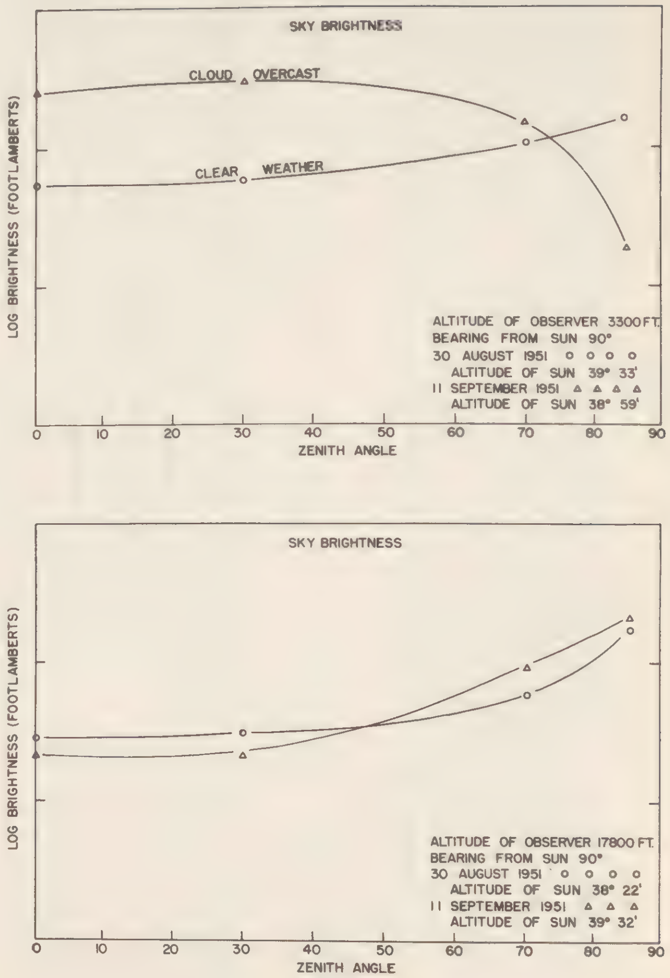

Figure 8.

CONCLUSION

These data indicate that, when operating under a broken overcast, the extreme variability existing in the brightness of the sky will preclude any rigorous quantification or the development of a strict predictive system for the specification of brightness under these conditions. It has been shown, however, that certain general relationships may be extracted to illustrate the differences between sky brightness under clear and cloudy weather conditions. It is believed further that when the overcast is solid it will be possible to specify all of the sky brightness relationships in a manner similar to that previously accomplished for clear weather conditions, provided the thickness of the overcast is included as one of the parameters.

SUMMARY

This report presents sky brightness data and data relating temperature and moisture content as a function of pressure taken under cloudy weather conditions. Comparisons are made between the brightness data and that gathered previously on clear days. Curves based on the Tousey-Hulburt theory of sky brightness are presented for comparison with the data curves. It was shown that below a cloud overcast, the customary brightness-zenith angle relationships are reversed. Beneath an overcast, the zenith rather than the horizon is the brightest portion of the sky.

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THE EVALUATION OF WINDSHIELD-WINDOW SOLID ANGLES WITH RESPECT TO HUMAN VISUAL FIELDS

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Data on "what man can see" provide a basis for comparing the boundaries determined by limitations of human capacity for vision and those imposed by the design of surrounding structures. Specifically, the objective is to evaluate the visibility from within the working space of a vehicle (land or air) on a quantitative basis, in relation to the field which a man could profitably use if no visual obstruction were present. The information thus made available to the design engineer may help improve provisions for seeing other vehicles and stationary objects in time to avoid collision.

In establishing criteria for evaluating visibility, the prime specification is that certain critical areas be free from all obstruction and provide vision of adequate quality (2, 7). For a motor vehicle, this critical area is defined as the region through which is to be seen the road and its shoulders ahead of the front wheels of the automobile. In a sub-critical area surrounding this region, minor obstructions may be permitted, such as motionless windshield wipers or vertical posts thin enough that they cannot block the lines of sight from both eyes simultaneously—say, less than 1-1/2 inches wide.

Provided these conditions for unobstructed vision are satisfied, the adequacy of the windshield-window area may be rated numerically on the basis of the total solid angle which it intercepts. With such a rating, however, certain regions of potential visibility must be excluded as non-essential, since they do not affect the safety of a ground vehicle. All other areas are more or less useful, at least potentially. A numerical score can thus be established as the ratio (W) of the USEFUL region that can be seen from the vehicle to a reference solid angle defined as the total USEFUL region which man could scan. That is:

$$W = \frac{\text{solid angle of total "useful" windshield-window area}}{\text{net "useful" solid angle of the human visual field}}$$

Such a score constitutes an absolute rating rather than a mere comparative grading, by relating the actual visibility from the vehicle to an ideal value—the maximum which could contribute to driving safety. It thus indicates the degree of improvement which may be possible in even the best of available automobiles.

For a motor vehicle, the non-essential regions to be excluded from consideration presumably include at least those shown in Figure 1, as follows:

(a) The "floor" area directly beneath the vehicle, bounded by the four wheels—since any object under the car can no longer be avoided; and

(b) a "roof" region overhead, above a certain critical angle of elevation--beyond which upward vision is not a safety factor. The critical angle may be taken, on several grounds, as about 30° upward from the horizontal.

Closed cars, in general, have no visibility in such regions; but for open-top vehicles, egregious errors would result from including in the score the large non-essential area overhead.

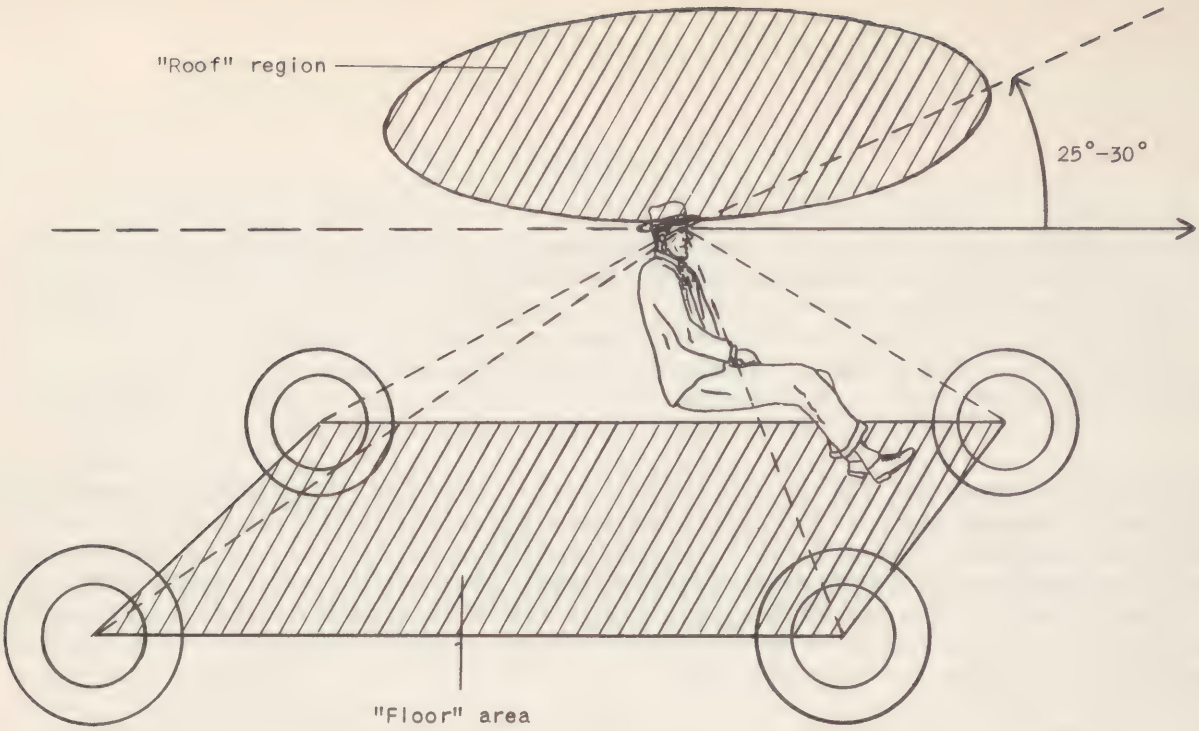


Figure 1. Excluded Areas. Diagram illustrating non-essential regions (shown shaded) to be excluded from any solid angle used in scoring vehicles.

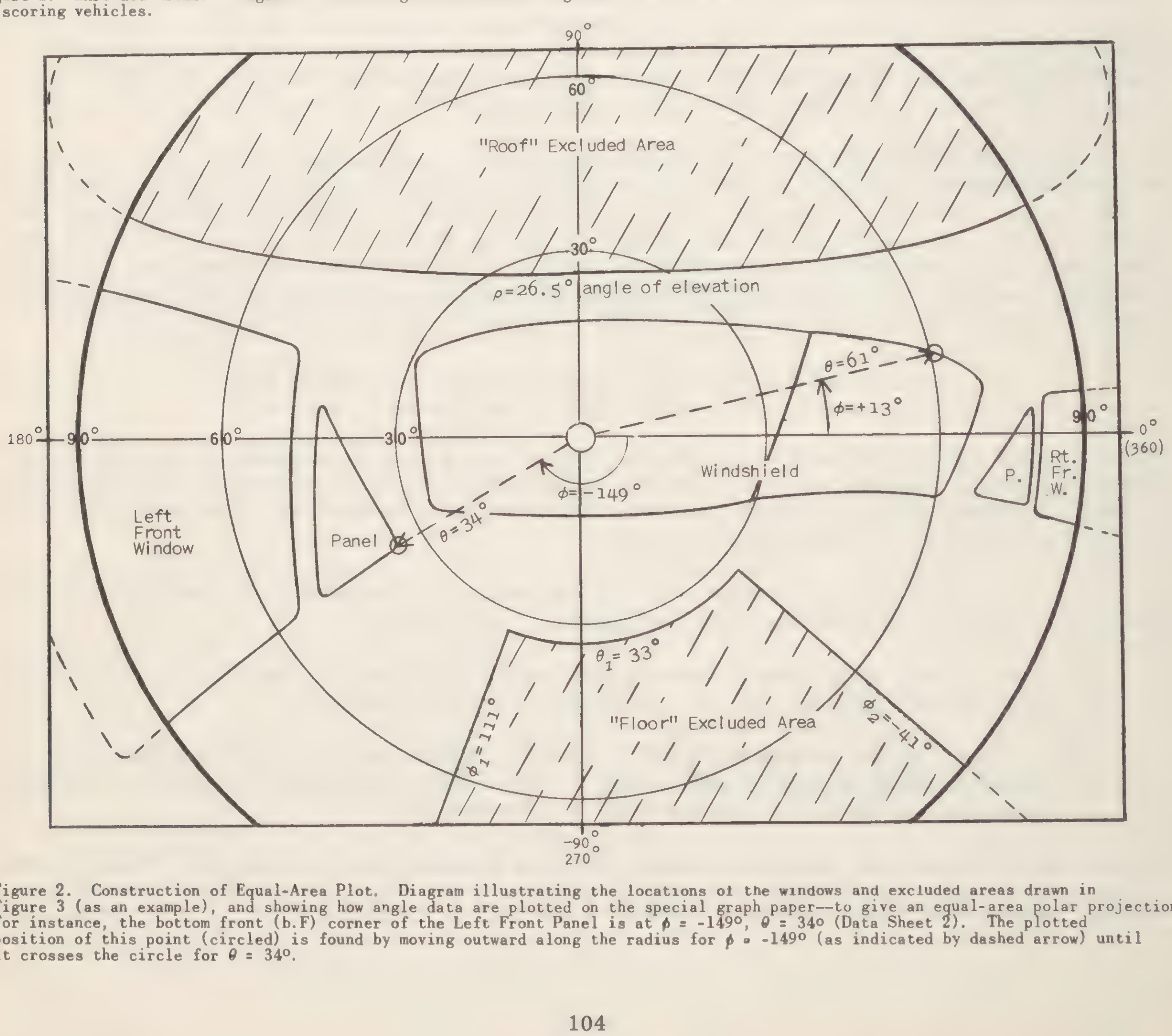


Figure 2. Construction of Equal-Area Plot. Diagram illustrating the locations of the windows and excluded areas drawn in Figure 3 (as an example), and showing how angle data are plotted on the special graph paper--to give an equal-area polar projection. For instance, the bottom front (b.F) corner of the Left Front Panel is at ϕ = -149°, θ = 34° (Data Sheet 2). The plotted position of this point (circled) is found by moving outward along the radius for ϕ = -149° (as indicated by dashed arrow) until it crosses the circle for θ = 34°.

The general problem now reduces to two parts: First, to measure the angular locations of the edges for the windshield and various windows and to calculate the (useful) solid angle included within them; second, to locate (in angular coordinates) the boundaries of the field of human vision and find the corresponding solid angle. The methods and techniques developed in our laboratory for the first half of the problem can only be outlined here; they are described in further detail in our reports (5, 6). In sum, our procedure is as follows:

The apparatus used for the vehicle measurements was a "goniometer"—seen in Figure 5—which was modified from a standard perimeter to measure the angular positions of points at the corners and edges of the windshield and windows, from a center of measurement set at the eye position of an average operator. A smaller, lighter, and simpler version of this device has just been designed and is under construction; it is considered much superior. The data read from the goniometer are the angular coordinates in the standard spherical system shown in Figure 6, measured from the forward horizontal line of sight as polar axis. The co-latitude is the field angle from this axis, and the azimuth is the meridian angle measured counterclockwise from the horizontal.

These data are plotted on special polar-coordinate paper, as explained in Figure 2, where the co-latitude is the radius outward and the meridian angle is the azimuth. This is then the projection on a plane of one hemisphere of the standard coordinate system, with the pole at the center. The excluded areas are also plotted on the same graph. The special paper which we drew up is shown in Figure 3; the co-latitude circles are non-uniform in spacing, in such a manner as to give an equal-area projection—that is, any area on the graph is directly proportional to the corresponding area on the coordinate sphere. Hence, solid angle is found by measuring the area on the graph with a planimeter (or by any other method) and applying a known calibration factor—here, 0.1 steradians per square inch.

Figure 3 is the graph for a typical passenger car (a 1950 Plymouth sedan), showing the forward hemisphere. The rear half is plotted separately in the same way. Any areas of interest can be measured directly from such a graph, and used to calculate the rating. This has been done for a number of vehicles, including passenger cars, trucks, and a bus. The scores found for the examples chosen range from 22% to 32%, where both extreme values are for passenger sedans (with detailed results given in Table III). It is thought that additional useful information may be obtained by computing the same score for the front half only—that is, dealing only with areas ahead of the driver's eyepoint. For our examples, the front-half scores were found to run from 31% to 42%; there was but little shift in the rating order of the vehicles, despite marked changes in the score differences between them.

The score used here was established to show what a man can see with respect to what should be visible to him. It thus requires measuring the extent of man's visual field. The results from this latter part of the problem showed that in the case of ground vehicles, it is not essential to introduce the limits of human vision explicitly, provided a properly designed rear-view mirror is available. The reason is that even if a man is restricted to very moderate movements of his head and eyes, he can see most of the useful region unaided, and all of it with the aid of a good mirror. Hence the total useful area—generally found as 7 to 7-1/2 steradians—is taken as the reference basis for scoring (i.e., 100%).

The situation is quite different, however, for aircraft—in which the Civil Aeronautics Administration is naturally interested—because in the air there is no region which can be excluded, since all are potentially useful. Consequently, the limits of man's vision are most important in finding the solid angle of the reference field in our rating, as well as indicating the bounds of profitable improvement in visibility—which are not even approached in current aircraft. In other respects, the evaluation criteria are the same for airplanes as for ground vehicles, except that the critical areas have different boundaries.

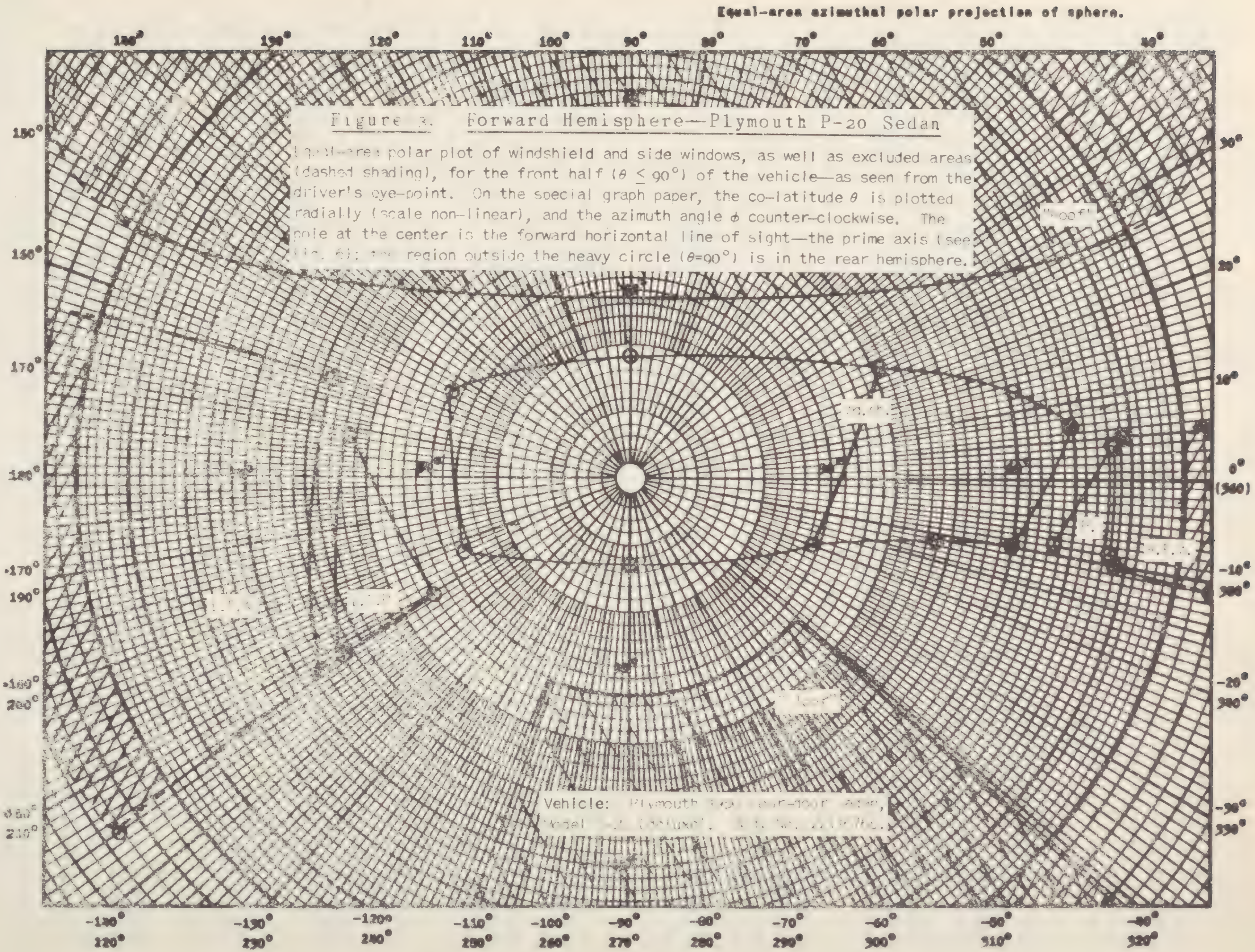


Figure 3. Forward Hemisphere—Plymouth P-20 Sedan

Equal-area polar plot of windshield and side windows, as well as excluded areas (dashed shading), for the front half ($\theta \leq 90^\circ$) of the vehicle—as seen from the driver's eye-point. On the special graph paper, the co-latitude θ is plotted radially (scale non-linear), and the azimuth angle ϕ counter-clockwise. The pole at the center is the forward horizontal line of sight—the prime axis (see Fig. 6); the region outside the heavy circle ($\theta=90^\circ$) is in the rear hemisphere.

The area which man can view is determined by his position and freedom of movement of head, eyes, and body. The seated position is assumed (as being normal for civil aircraft and ground vehicles), and it is specified that no movements of trunk or body will be required for proper visibility. Five conditions of head and eye movement were defined, ranging from maximum movements to none. From data (1) taken on a few subjects, the average angular limits of the peripheral field of vision and of the range of fixation were found in the horizontal and vertical planes (meridians), for each condition of viewing (see Table I). Figure 4 shows some of the angular relations. From the four points—up, down, right, and left—on the boundary of each visual field, a mean value for the solid angle subtended by the field was calculated to a good approximation (see Table II), and corrections to these results were approximated for the obstruction of the observer's own body.

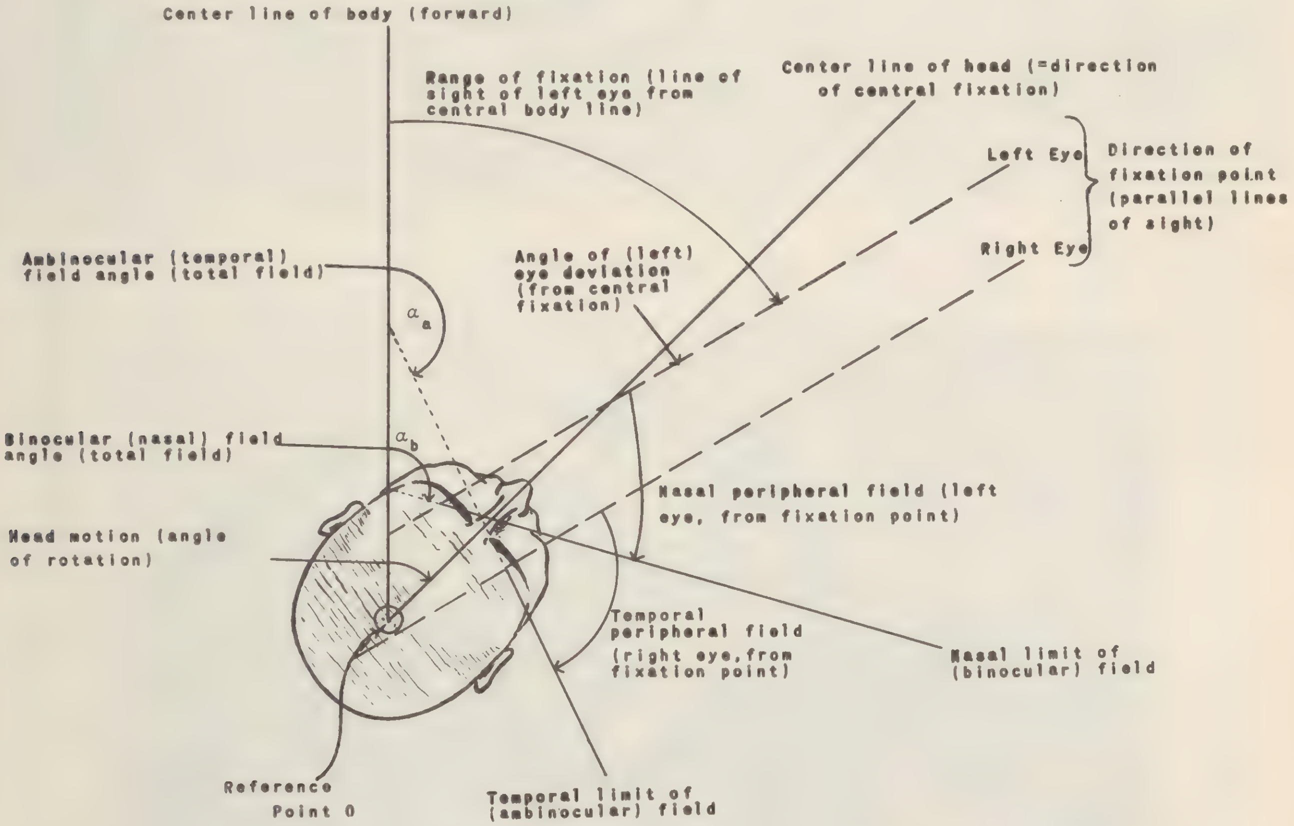


FIGURE 4. Showing horizontal field angles and other angular ratios (Scale about 1:4)

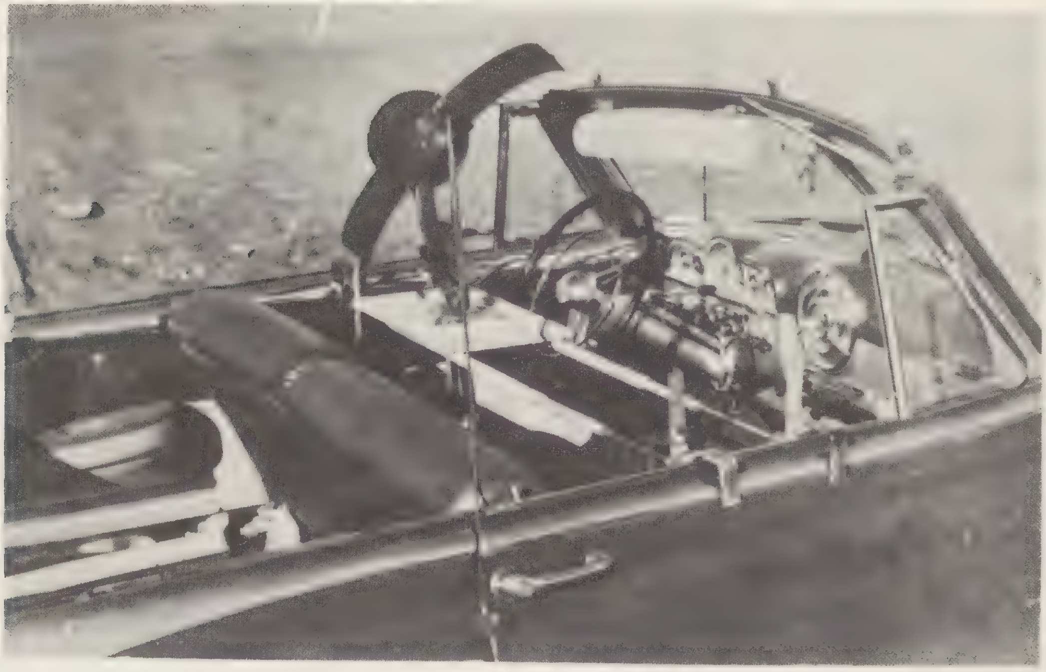
Figure 4. Showing horizontal field angles and other angular ratios (Scale about 1:4).

The reference field of vision which we chose to use (others might select differently) was based upon a standard condition of moderate motions of head and eyes, such as are commonly used in everyday seeing. Specifically, eye deviations of 15° in any direction from central fixation (the forward horizontal polar axis) was selected as one restriction,* while head movements were limited to those of 30° up or down and 45° to either side, which are performed easily and naturally. The sum of these head and eye motions gives the field of acute vision for both eyes at once—i.e., the binocular range of fixation—as:

60° horizontally, to either side;
45° vertically (up or down).

*Because fixation points do not usually vary more than this amount in the performance of ordinary visual tasks (4).

(a) Component parts of apparatus, and associated equipment.



(b) Goniometer as mounted between doors of automobile.

Figure 5. Goniometric apparatus for measuring windshield and window angles in working spaces of vehicles. The goniometer is modified from a standard perimeter, and is in the vehicle with its eye-point where the eye of the operator would be. The telescoping rod through this eye-point is extended to the windshield location to be measured, the perimeter target is moved to the opposite end of the rod, and the angles are then read from the scales on the perimeter.

TABLE I : FIELD ANGLES OF HUMAN VISION

Condition of Movement Permitted	Type of Field	Horizontal Limits: (Temporal) Ambinocular Field (each side)	Horizontal Limits: (Nasal) Binocular Field (each side)	Vertical Limits: Field Angle Up	Vertical Limits: Field Angle Down
(a) Head and eyes: moderate movements, assumed as: Eyes: 15° Right or Left, 15° Up or Down; Head: 45° Right or left, 30° Up or Down	Range of fixation	60°		45°	
	Eye deviation (assumed)	15°	15°	15°	15°
	Peripheral field from point of fixation	95°	(45°)	46°	67°
	Net (peripheral) field from central fixation	110°	60°***	61°	82°
	Head rotation (assumed)	45°	45°	30°*	30°*
	Total peripheral field (from central body line)	155°	105°	91°	112°**
(b) Head fixed, Eyes fixed (central)	Field of peripheral vision (central fixation)	95°	60°	46°	67°
(c) Head fixed, Eyes maximum deviation	Limits of eye deviation (= range of fixation)	74°	55°	48°	66°
	Peripheral field (from point of fixation)	91°	Approx...(5°)	18°	16°
	Total peripheral field (from central head line)	165°	60°***	66°	82°
(d) Head maximum movement, Eyes fixed (central with respect to head)	Limits of head motion (= range of fixation)	72°	72°	80°*	90°*
	Peripheral field (from point of fixation)	95°	60°	46°	67°
	Total peripheral field (from central body line)	167°	132°	126°	157°**
(e) Head and Eyes: both maximum movement	Limits of head motion	72°	72°	80°*	90°*
	Maximum eye deviation	74°	55°	48°	66°
	Range of fixation (from central body line)	146°	127°	128°	156°**
	Peripheral field (from point of fixation)	91°	Approx...(5°)	18°	16°
	Total peripheral field (from central body line)	237°	132°	146°	172°**

* Estimated by the authors on the basis of tests on a single subject.

** Ignoring obstruction of body (and/or knees if seated). This obstruction would probably impose a maximum field of 90° (or less, seated) directly downward; however, this would not apply at either side, where the potentiality of seeing further downward if the body were transparent extends the total area of the visual field markedly.

*** Maximum possible peripheral field (equal to that achieved with maximum eye deviation). This is limited by the anatomy of the structures around the eye (nose, cheeks, brows, etc.). The figures in brackets on the line preceding each occurrence of this note are calculated values, chosen to result in the maximum limit thus indicated.

Table I. Horizontal and vertical (angular) limits of the human visual field.

All data except as noted are from Hall and Greenbaum (reference 1).

The "**ambinocular**" field is defined here as the *total* area which can be seen with two eyes--but not in all parts by both at once. At the sides, it includes "uniocular" regions visible to the right eye but not the left, and vice versa. It is bounded only by the temporal field-limit of each eye.

The term "**binocular**" is here restricted to the narrower, more central region which can be seen by both eyes *simultaneously* (stereoscopic vision). It is bounded by the nasal field-limits of the eyes. In other words, the *binocular field* is the area where the individual (monoculate) fields of the eyes overlap each other, while the *ambinocular field* comprises in addition the marginal regions visible to only one eye.

TABLE II: SOLID ANGLES OF HUMAN VISUAL FIELDS

Condition of Movement Permitted	Type of Field	Solid Angle of Total Field: Ambinocular Angle (Sterads)	Solid Angle of Total Field: Ambinocular % of 4π (= % of sphere)	Solid Angle of Total Field: Binocular Angle (Sterads)	Solid Angle of Total Field: Binocular % of 4π (= % of sphere)	Unobstructed Solid Angle Seated: Ambinocular Angle (Sterads)	Unobstructed Solid Angle Seated: Ambinocular % of 4π (= % of sphere)	Unobstructed Solid Angle Seated: Binocular Angle (Sterads)	Unobstructed Solid Angle Seated: Binocular % of 4π (= % of sphere)
(a) Head and Eyes: moderate movements (as indicated in Table I)	Range of fixation	2.40	19.1%	2.40	19.1%	2.40	19.1%	2.40	19.1%
	Total peripheral field	9.48	75.4%	7.70	61.3%	8,88	70.7%	7.10	56.5%
(b) Head fixed Eyes fixed (central)	Peripheral field (Total)	4.38	34.9%	2.97	23.6%	4.30	34.2%	2.89	23.0%
(c) Head fixed Eyes maximum deviation	Range of fixation	3.58	28.5%	2.75	21.9%	3.51	27.9%	2.68	21.3%
	Total peripheral field	7.48	59.5%	3.77	30.0%	7.26	57.8%	3.55	28.2%
(d) Head maximum movement Eyes fixed (central with respect to head)	Range of fixation	4.99	39.7%	4.99	39.7%	4.69	37.3%	4.69	37.3%
	Total peripheral field	11.69	93.0%	10.75	85.5%	10.88	86.5%	9.93	79.0%
(e) Head and Eyes: both maximum movement	Range of fixation	11.27	89.7%	10.55	83.9%	10.46	83.2%	9.74	77.5%
	Total peripheral field	12.28	97.7%	11.21	89.2%	11.42	90.9%	10.36	82.5%

Table II. The solid angles intercepted by the fields of human vision, calculated from the field limits of Table I. (See appendix for method of calculation.)

The "solid angle of the total field" (as tabulated) includes any visible areas of the body (but not the head). That is, the "external" field visible *beyond* the body is less than this "total field" value by whatever solid angle is obstructed by the position of the body.

The "unobstructed solid angle" has been corrected for the obstruction of the body when seated. From the "total field" value was subtracted the solid angle intercepted (from the eye-point) by a region extending from hip to hip sideways, and from the knees to the downward limit of the vertical field (when this extends past the knees).

For a standing position, the "unobstructed" field would be intermediate between the values given.

Anthropometric data from Randall et al. (reference 3) were used to find the body angles from which the body obstruction corrections were calculated.

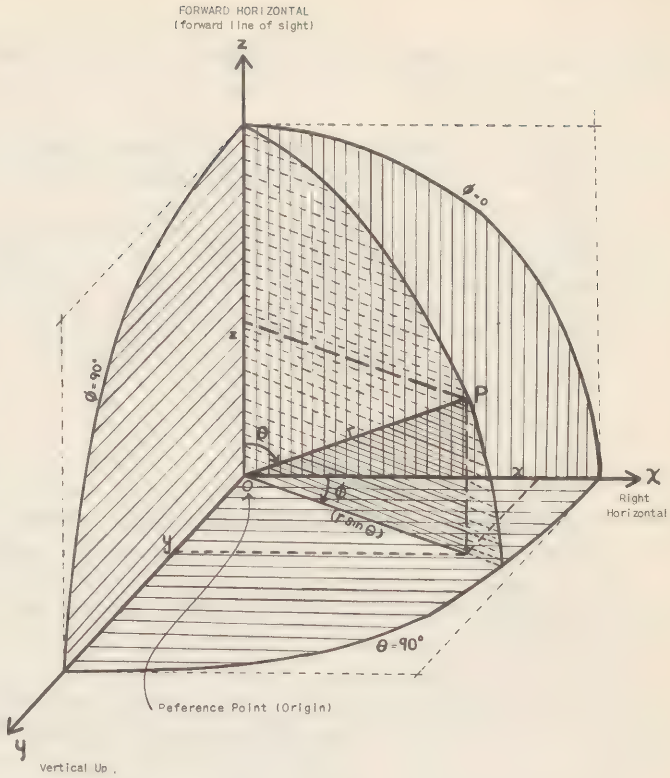


Figure 6. Coordinate System. Spherical coordinate system and reference axes used throughout all mathematical derivations and calculations. The reference point (0) at the origin is the center of rotation of the head. (The forward direction [z-axis] is along the center line of the body.)

The corresponding solid angle is:

2.40 steradians (19.1% of a sphere), which is unaffected by body obstruction, since the range does not extend downward to the knees.

Surrounding the region of fixation is an additional peripheral field, and the sum of these is the total (peripheral) field which can be scanned in any way. While most of the region is visible to both eyes simultaneously (binocular field), there are areas at the edges which can be seen by only one eye or the other. The extent of this total region visible to a two-eyed man—named the ambinocular peripheral field—is:

155° horizontally, to each side;
91° upward; 112° downward.

The solid angle subtended amounts to:

9.48 steradians (75.4% of a sphere),

which is reduced by body obstruction to:

8.88 steradians (70.7% of a sphere).

The total peripheral field is all potentially useful in detecting and avoiding collision with outside bodies, even though vision is by no means acute all through it, because a vague image seen near an edge signals the presence of another object which can then be identified by turning to fix the gaze on it. Thus many objects are seen which might otherwise be unobserved.

The reference solid angle we have used for rating is that of the ambinocular total peripheral field (uncorrected for body obstruction) of 9.48 steradians. It is of interest to note that the ambinocular range of fixation for maximum head and eye motions (even after correction) is large enough (10.46 sterads) to more than cover the full reference field; consequently, an object seen anywhere in the peripheral field for normal head and eye motions can be fixated—in most regions with both eyes—by using maximum motions.

Taking the above as the reference value, the rating score W was calculated for a number of transport aircraft, based on windshield-window measurements carried out photographically by Pigman and Edwards (2) of C.A.A. Table IV gives the results. The highest rating shows that the solid angle of total windshield-window area represents only 21-1/2% of that in the reference field of human vision. Scores as low as 14% are found among the six types of transport airplanes, all now operating successfully. The question of what score might be considered fully adequate or constitute excellent visibility cannot be settled at this time. However, the relatively high incidence of near misses in flight because of failure to see other aircraft indicates that some improvement in visibility should be achieved.

NOTE: The work on this project at the Civil Aeronautics Medical Research Laboratory is conducted under the auspices of the Commission on Accidental Trauma of the Armed Forces Epidemiological Board, with support by the Office of the Surgeon General, Department of the Army.

TABLE III: RATINGS (W) FOR SEVERAL MOTOR VEHICLES

	Full Field	(Front Half)
Plymouth 1950 Sedan, four-door	32%	(42%)
Chevrolet 1948 Sedan, four-door	22%	(31%)
White Truck Cab, Model 3014	28%*	(37%)
Reo Truck Cab, Model F-22 S-1L	25%*	(35%)
White Bus (1952), Model 1150 DW	27%**	(42%)

*Omitting rear-view window.
**Omitting rear-view window and all but three of 18 back windows.
The "Front Half" score is calculated for the forward hemisphere considered alone—i.e., using only those parts of both reference and vehicle fields which are ahead of the driver's eyepoint. The rear windows are omitted from the "full field" score of these commercial vehicles because in practice they are generally obstructed.

TABLE IV: RATINGS (W) OF WINDSHIELD AREA IN STANDARD TRANSPORT AIRPLANES

	Douglas DC-3	Douglas DC-4	Douglas DC-6	Lockheed Constellation	Convair 240	Martin 2-0-2
*Solid angle of total windshield area (steradians)	2.041	1.478	1.310	1.632	1.972	1.328
*Fraction of total solid angle in sphere (12.57 steradians)	16.25%	11.76%	10.4%	12.4%	15.7%	10.6%
Fraction (W) of solid angle in human visual field**	21-1/2%	16%	14%	17%	21%	14%

*Data directly from Pigman and Edwards (reference 2).
**Field of human vision taken for this calculation as the uncorrected peripheral ambinocular field for moderate movement of head and eyes (see Table II), which covers 9.48 steradians solid angle (75.4% of sphere). This is very nearly equal to the binocular fixation field of 9.74 steradians solid angle (77.5% of sphere) found from the range of fixation when maximum head and eye movements are permitted (Table II), after correction for body obstruction.

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Discussion:

Dr. Rose commented that he considered Dr. Sutro's approach to vision out of aircraft a very valuable one, and expressed the hope that there would soon be similar evaluations of military aircraft. He thought, however, that proper weighting of Dr. Sutro's data would make them more useful. He noted that Dr. Sutro had already done this to a certain extent by giving the bottom and the top weight zero and by recomputing his data for the front half only. Dr. Rose suggested that in an aircraft, for instance, everything that obstructs vision to the horizon has a higher obstructing value, and forward angles of 10°, 20°, or 30° have a higher value than those around 90°; therefore, it might be possible to weight the data on the basis of how much vision means for orientation on the likelihood of an aircraft occurring in a particular area. Dr. Rose thought Dr. Sutro's data could be made more helpful if computed in both ways, giving the unweighted as well as the weighted results.

Dr. Sutro replied that the matter of weighting the data had been considered, of course. However, in order to avoid controversy on the matter of how various areas should be weighted, it was decided to leave the data unweighted and to attempt to give the weighting by defining the critical and sub-critical areas and recomputing the data for particular areas of the vehicle—for example, the front half—rather than attempting to assign a specific weight to every possible region. Dr. Sutro said he would be very glad to recompute the data for anybody who would tell him what weight should be assigned to each area.

CDR Wagner commented that similar studies had been done on military aircraft, both by the Air Force and by the Navy. The same difficulties had arisen. Such studies are useful only if one can evaluate and weight the different areas of the aircraft, but no easy way of doing this had been worked out. CDR Wagner had no solution to offer Dr. Sutro.

THE EVALUATION OF APPROACH AND RUNWAY LIGHTING WITH THE KINORAMA*

F. C. Breckenridge
National Bureau of Standards

1. INTRODUCTION

The Bureau of Aeronautics has sponsored the development by the National Bureau of Standards of a device with which a pilot can evaluate the guidance provided by a system of approach and runway lights without leaving the ground. The kinorama, as this device is called, allows the pilot to see an approach- and runway-light configuration in apparent motion as he would see it if he were flying over it in fog. Tests with an early model of the kinorama have given promising results indicating that simulated approaches made with the device afford reliable information for the evaluation of approach- and runway-light configurations. While such an evaluation is not a complete substitute for actual flight testing for the final approval of a system, it is, nevertheless, inexpensive, objective, free from hazards, and not dependent upon the erratic occurrence of fogs. In this report a tentative program is proposed for making certain of the validity of the kinorama results and for carrying out evaluations on the more important approach-light configurations.

2. STATUS OF APPROACH LIGHT EVALUATION

It has been assumed by some that the approach-light problem has been solved by the adoption of national (1) and international (2) standards for approach-light configurations. The paper which contains the U.S. Standard, "Aids to Air Navigation and Landing--Draft U.S. Standard on Approach Lighting," Air Coordinating Committee No. 59/10.6A contains a comment that is pertinent to this view. In Exhibit B (3) of that draft, Mr. R. H. Clinkscales, Member for the Civil Aeronautics Board on the Technical Division of the Air Coordinating Committee, after summarizing the draft, concludes, "In view of the above it is apparent that:

(a) there is no single national standard for approach lighting but rather, there are three standards;

(b) the adoption of the three systems may adversely affect safety."

This view is generally held by the engineers who advised the U.S. delegates during the formulation of the I.C.A.O. and the U.S. "standards." Nearly every one of these engineers would agree that the compromises adopted were the most satisfactory that could be worked out in the circumstances, and there is general agreement that further work is needed to establish an adequate technical basis for a long-range standard.

The further study of the approach-light configuration problem is warranted from three points of view:

1. In view of the large variation in the costs of the three systems described in ACC 59/10.6A, it is probable that the program proposed in this report will show means of accomplishing the needs of all the agencies with substantial savings on the more expensive installations.

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*A report to the Vision Committee on a project sponsored by the Bureau of Aeronautics.

2. There is a strong probability that the proposed study will provide a basis for developing the single standard that is universally desired.

3. There is still a worthwhile probability that the improvements which can be introduced, or the simplification resulting from a single system, will reduce accident losses.

3. DESCRIPTION OF KINORAMA

The basic principle of the kinorama, which was conceived jointly by Mr. A. L. Lewis of the Bureau of Aeronautics and the author, is to represent an approach-light configuration by a small movable model whose motions are the reciprocal of those which a plane would have in landing over the lighting system. Because the pilot's reactions are the true test of any system being evaluated, the motions of the model must be those which would normally appear to follow the pilot's use of his controls. In the kinorama, the approach lights are represented by fluorescent miniatures of lighting units mounted on an endless tape which moves continuously toward the observer, simulating the plane's forward motion over the approach and runway lights. For lighting systems comprised of units that are all in one plane, it is only necessary to represent the lights by small spots of fluorescent material on the surface of the tape. However, for systems like the slope-line system in which the third dimension is significant the lighting units are represented by miniatures which include the third dimension. This tape is shown in the schematic drawing (Figure 1) but was not in place when the photograph for Figure 2 was taken.

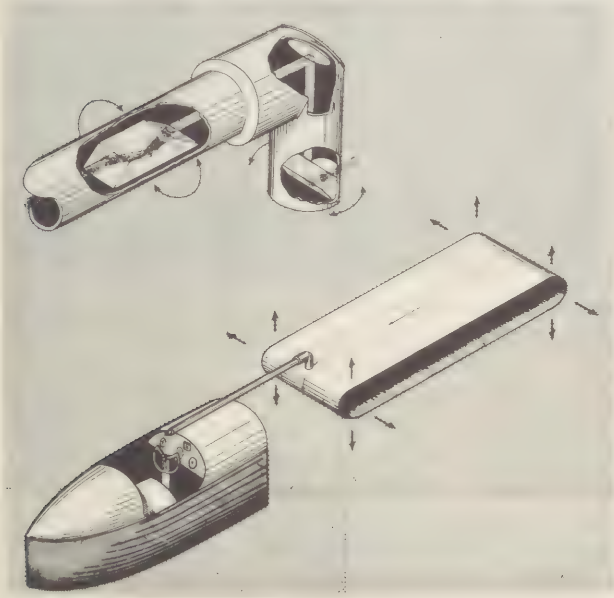

Figure 1. Schematic diagram showing kinorama motions simulating those of airplane by reciprocal movements of endless tape, on which approach-light system is represented, and the rotation of prisms as shown in the cutaway.

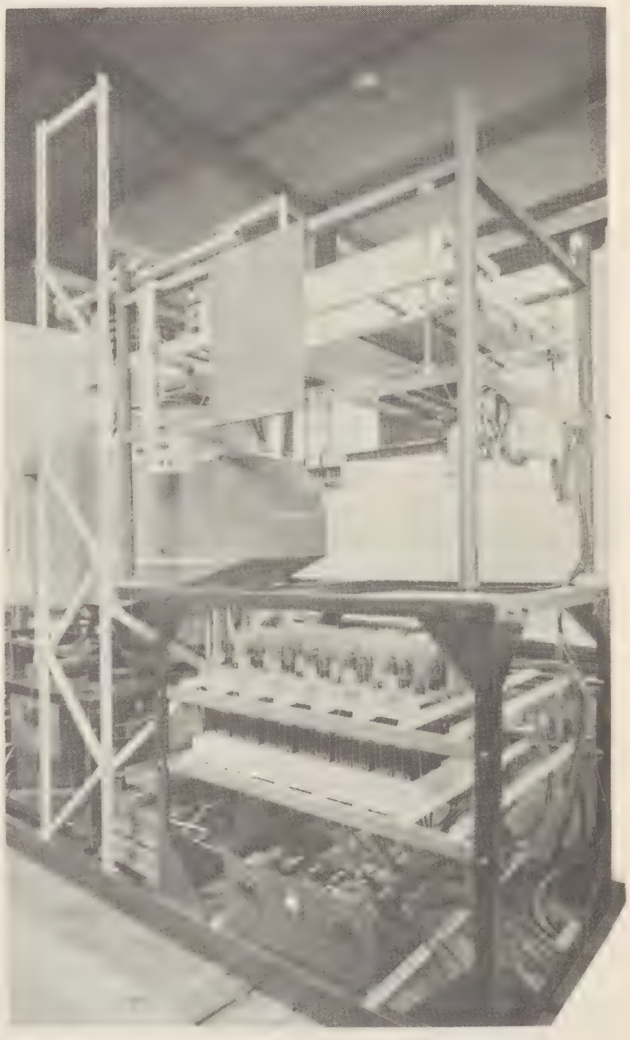

Figure 2. View of kinorama showing table assembly which provides forward, crosswise, and vertical movements.

To simulate the lighting system on a sufficiently small scale so that over-all dimensions are kept within practicable limits, the point of observation must be placed very near to the tape in order to make the view correspond to that from points along the approach path. This is accomplished by the use of a telescope with negligible magnification and an objective approximately 0.5 inch in diameter. With a larger objective, it would not be feasible to bring the point of observation sufficiently near the lighting units and only the first stages of an approach could be simulated. With a telescope of sufficient length the pilot can sit in his seat normally and see the lights as if he were coming down among them. The telescope also simplified the problem of simulated banking. It was only necessary to install a dove prism at a suitable location in the telescope and rotate this prism to obtain a realistic simulation of a lighting system as seen from a banking plane. The eyepiece of the telescope is visible above the Link cockpit in Figure 3.

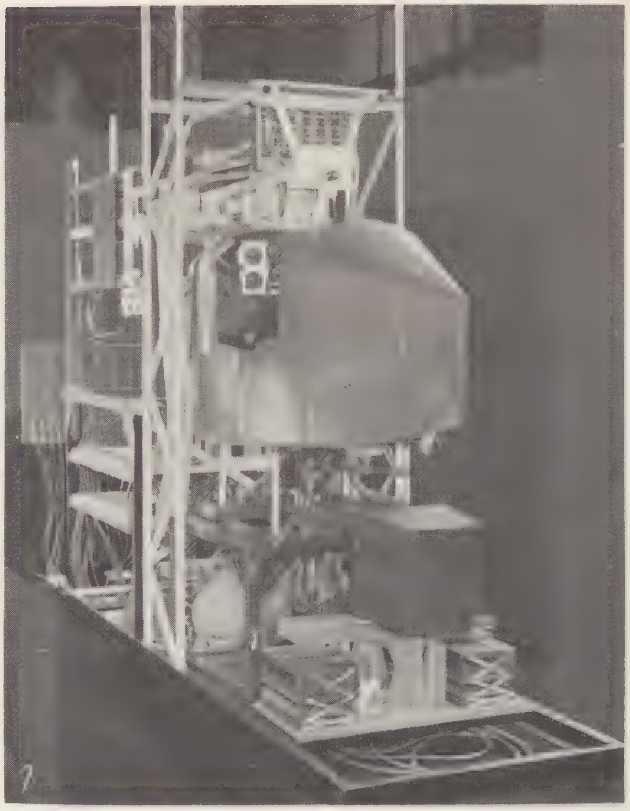

Figure 3. View from pilot's end showing telescope assembly which contains mechanism for presetting and moving prisms and cockpit cutoff to simulate banks, yaws, and pitches.

In the prototype kinorama, the cockpit, instruments, and controls of a Link trainer take the place of those of an airplane. True vertical and horizontal motions, as well as the forward motion, are provided in the table assembly. All the angular motions are simulated optically in the telescope assembly which simplifies the mechanical design and makes it possible to provide the desired yawing movements with less width. Servomotors control all movements of the kinorama including those of a recorder which provides a permanent record of each "landing." Special equipment allows automatic presetting of any one of nine initial landing states—that is, the selection of one of nine combinations of three altitudes with three transverse positions, combined with a predetermined yaw, bank and pitch for each state. This flexibility of presetting is sufficient to meet the needs of a wide variety of landing problems.

The kinorama is now substantially completed. Some temporary parts were used to expedite the latter part of its construction and these are now being replaced, but it is hoped that this can be completed during the course of the program proposed in this report. Further efforts should be made to improve the tracking of the belt and the simulation of fog, but neither of these matters is sufficiently serious to interfere with the starting of the program.

4. VALIDATION OF KINORAMA

When a description of the kinorama was presented to the Illuminating Engineering Society at its Annual Technical Conference in September 1952, the most pertinent comment offered was that the kinorama should be validated before it is used to evaluate approach- and runway-light configurations. This view was later discussed in a conference with Dr. Franklin V. Taylor of the Office of Naval Research and Professor Alexander C. Williams of the Aviation Psychology Department of the University of Illinois. It was the sense of this conference that such a validation was important and that a considerable amount of preliminary

work might have to be done before it would be practicable to start the evaluation of the approach-light systems. Subsequent discussions with Professor Ray C. Hackman, a consultant provided by the Office of Naval Research, developed the probability that considerable time can be saved by first making an exploratory study to learn the characteristics of the kinorama which must determine the research designs for the subsequent validation and evaluation work. For parts of this study "naive" observers can be used, that is, observers who are not pilots. Special configurations designed to develop the desired information with reference to the reproducibility and interpretation of the kinorama results will be needed.

The program for the validation of the kinorama should not be decided until the exploratory program has been completed, but the following four criteria appear to be available.

1. Agreement of the performance as determined with the kinorama with the guidance inherent in the configuration as shown by an analysis of the spatial and time elements involved.

2. Agreement of the performance as determined with the kinorama with the results obtained in flight-testing similar configurations.

3. Agreement of the results obtained with the kinorama with the extent of the subject's experience in using approach lights.

4. Agreement of the objective results with the subjective experiences of the pilots.

Of these, criterion 2 would be the most satisfactory if the flight-test results available were adequate in number of cases and reliability. In neither respect, however, can the flight-test results be called adequate and such validation of the kinorama as can be based on these tests alone can be no more reassuring than the flight tests on which it is based. A considerable support for results based on criterion 2 may be obtained, however, from criterion 1 and if all four criteria agree we can accept the kinorama results as sufficiently validated.

5. EVALUATIONS WITH THE KINORAMA

It is proposed that the first evaluation work be a comparison of the three U.S. standard systems from the standpoint of their use by naval types of aircraft, especially the single-engine craft. The subsequent program will depend upon the results of this initial work. Should the results of this work indicate that system A or B might be satisfactory for use with these aircraft, the problem should be explored further since, if it should prove possible to use one of the less expensive systems, substantial savings for the Bureau of Aeronautics could be achieved. In this case it would be desirable to continue the work by comparing with the British crossbar system whichever system, A or B, gave the better results. This could lead to evidence that the more expensive British system is not warranted or that the present U.S. standards A and B require further improvement.

If the evaluations of systems A, B and C confirm the results of the engineering analyses and the flight tests made at Patuxent, it will then be desirable to study configuration C to determine if any simplification of this system can be made without loss of the guidance provided the pilot. If such simplifications are possible, this too will result in a saving in the cost of installing future approach-light systems. Such a result should also lead to a reconsideration of U.S. standards A and B and ultimately, perhaps, to the replacement of these standards by standard C in its present form or in an improved form.

The initial evaluations of systems A, B, and C should be made with the complete systems as described in the U.S. Standard, but any attempt to simplify any of these systems

in the interest of economy or to improve one of them in the interest of safety is likely to achieve its purpose sooner if tests are first made on the basic elements of configurations to establish the principles underlying visual guidance for landing aircraft in fog.

There are no doubt many ways of organizing a program for the proposed validation and evaluations, but whatever the organization provision must be made for three essential functions if the results are to gain general acceptance. There must be a definite sponsorship so that anyone may know what agency takes responsibility for the work. There must be a psychological control because the crucial problems are psychological. There must be an operating agency to provide a controller for the tests, to carry out the statistical analysis of the records in accordance with the directions of the psychological control, and to service the kinorama when necessary.

6. SCOPE OF PROGRAM

While it is not possible to make a reliable calculation of the number of simulated approaches that will be required for the evaluation work proposed until the exploratory tests have been carried out, some discussion of the scope of the work is essential for any intelligent planning. On the basis of the testing done with the laboratory model of the kinorama, 7500 "approaches" seems a reasonable estimate of what may be required. It is of interest to consider this estimate in comparison with a flight-test program. The experience at the Landing Aids Experiment Station at Arcata, California, indicated that between 600 and 650

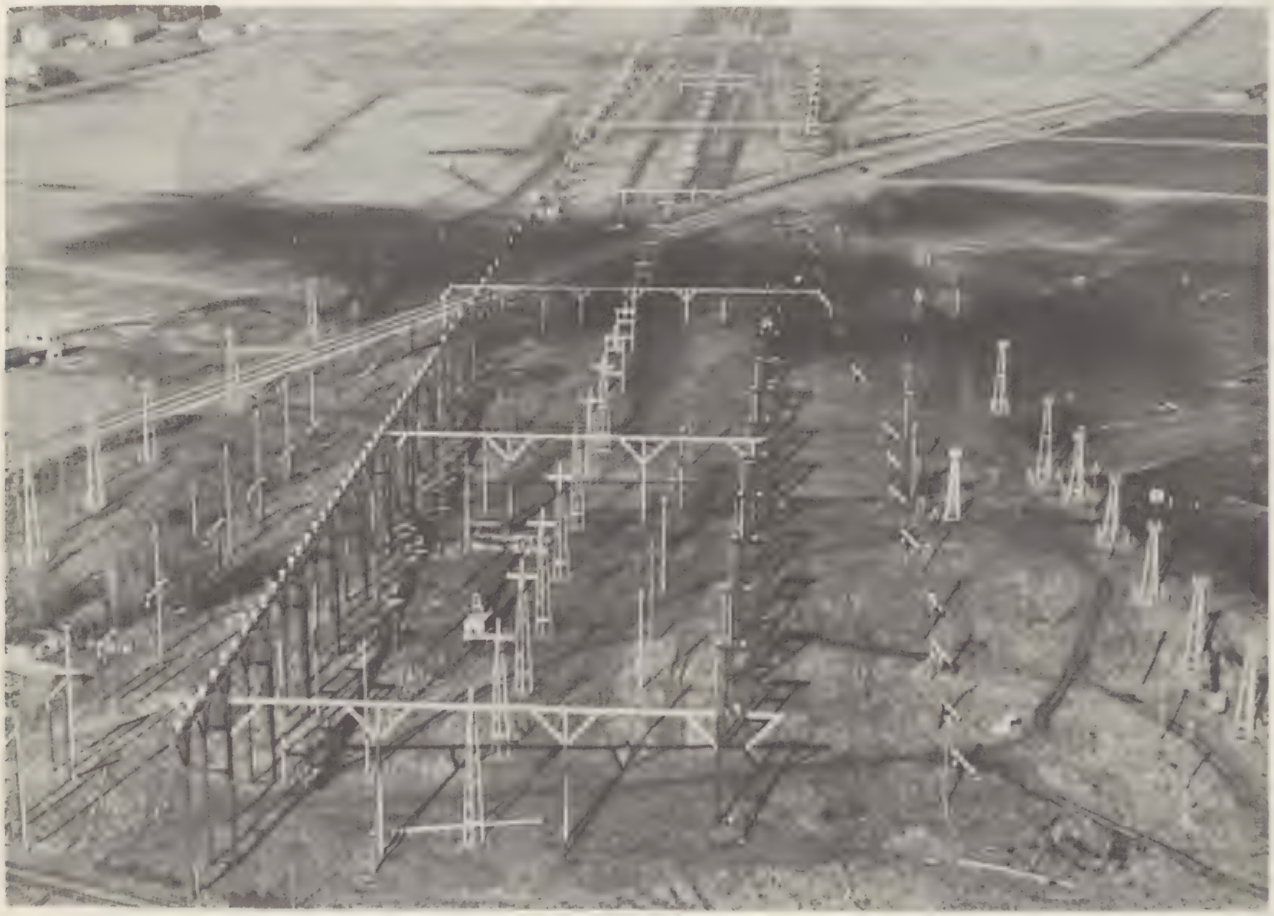

Figure 4. Approach-light installation for flight testing at the Landing Aids Experiment Station, Arcata, California. The kinorama is designed to reduce the needs for such elaborate installations and costly flight testing.

approaches in fog could be made per year at that station which was maintained for that purpose alone in the most favorable location in the United States. It would have taken Arcata twelve years to have made as extensive a study as is contemplated in this estimate. It would, of course, take much longer at an air station having less foggy days especially if the station is engaged in other projects that are considered important enough so that some fogs go by without use. Figure 4, which shows the installations used at Arcata for the flight tests of 1949, gives an impression of the costliness of flight-testing configurations of approach lights.

The proposed estimate allows for the use of a large number of pilots, between 50 and 100, representative of naval, air force, and civil flying, but no one of these would need to devote more than one or two days' time to the work and this could be done in several short intervals arranged to interfere as little as practicable with his other duties. In this brief time the pilots can each make the equivalent of 90 approaches. Flight testing in fog requires so much special training with the facilities under test that it would be quite impracticable to utilize such a large representative group of pilots and the pilots assigned the duty must devote weeks, probably months, to it.

With the kinorama the research can be designed to cancel out extraneous factors and base the comparisons on highly comparable conditions. Even if a twelve-year study were carried out at Arcata, it would not be possible to rival the precision with which these two essential elements of a sound testing procedure can be readily attained with the kinorama. It is not necessary to emphasize the elimination of hazards through the use of the kinorama.

Notwithstanding the advantages of the kinorama for evaluating the relative guidance to be obtained by different configurations of approach lights, it must be kept in mind that the kinorama evaluations do not eliminate the need for final flight tests before any innovations are placed in service. If, however, the kinorama can take over 90% to 95% of the testing, it will make a great contribution to economy and expedite the testing by a factor of 5.

* * * * * *

This report represents the views of the technical staff which has produced the kinorama and should not be understood as implying any policies upon the part of the Bureau of Aeronautics. The report is being presented to the Vision Committee in the hope that its experience in dealing with analogous problems may enable it to make suggestions for improving whatever program may be adopted.

REFERENCES

(1) A.C.C. doc 59/10.6, Exhibit A.

(2) Amend. 6 Sect 2.2.1.2 to Annex 14 to Convention on Civil Aviation, I.C.A.O. 1953.

(3) A.C.C. doc 59/10.6, Exhibit B.

Discussion:

Dr. Blackwell asked Mr. Breckenridge to comment on his criteria for successful landings.

Mr. Breckenridge explained that a recorder records the projection of the path followed both vertically and horizontally and a number of different criteria are applied to analysis of that path. As for the validation, several principles have been used. For example, a configuration can be analyzed geometrically to see whether it has inherent in it a certain type of guidance. The results obtained by highly experienced pilots are compared with results obtained by inexperienced pilots. If the experienced pilots obtain better results than the inexperienced pilots, it indicates that the apparatus is behaving normally. Also, the results obtained can be compared with subjective impressions of pilots.

Mr. Breckenridge then stated that his group would welcome suggestions from members of the Vision Committee on the development of the Kinorama, criteria for its validation, etc.

A BROAD-BAND-BLUE LIGHTING SYSTEM FOR
RADAR APPROACH CONTROL CENTERS

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The general public recognizes the darkened room surrounding a cathode ray tube as a synonym for radar. This darkened room is the conventional solution to the problem of improving the visibility of radar targets on bright trace cathode ray tubes. This solution does give fair scope visibility, but the operators must work in the dark, and operations must be discontinued whenever light is needed for maintenance of the equipment.

The present report describes a polychromatic system of lighting radar centers that provides improved scope visibility, permits the use of an illuminated working environment, and makes possible 24-hour radar operations. The basic principle of this lighting system is frequency sharing. A broad band of blue light (the shorter wavelengths of the visible spectrum) are allocated for ambient room illumination and the remaining portion of the visible spectrum is used for CRT reading and for other special purposes.

The general lighting requirements of an Air Force Radar Approach Control Center for both the present and future are as follows:

1. Maximum CRT visibility.
2. Adequate legibility of secondary displays.
3. Sufficient illumination for maintenance and supporting personnel so that 24-hours-a-day operation is possible.
4. Sufficient illumination for reading, writing, and free movement of personnel.
5. Sufficient illumination for training and research functions.

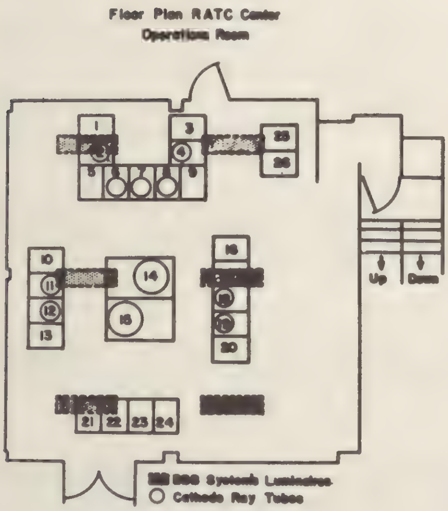

Fig. 1. Floor Plan of the RAPCON Center Operations Room at W-P AFB, showing the location of the 11 CRT displays and the overhead blue light sources.

In the past the last four requirements have often been incompatible with the first, since the usual white room illumination decreases the signal-noise ratio of the CRT through reflections and excitation of the phosphor. In addition, the operators' visual sensitivity is decreased because their eyes are light adapted.

The cornerstone for the development of an adequate lighting system is a consideration of the classes of phosphors used in the radar displays. The Radar Approach Control Center at Wright-Patterson Air Force Base uses four classes of CRT's in eleven indicators, slaved to four radars. The positions of the CRT's are indicated by the circles in the floor plan in Fig. 1. The indicators face four directions, making the elimination of surface reflections difficult.

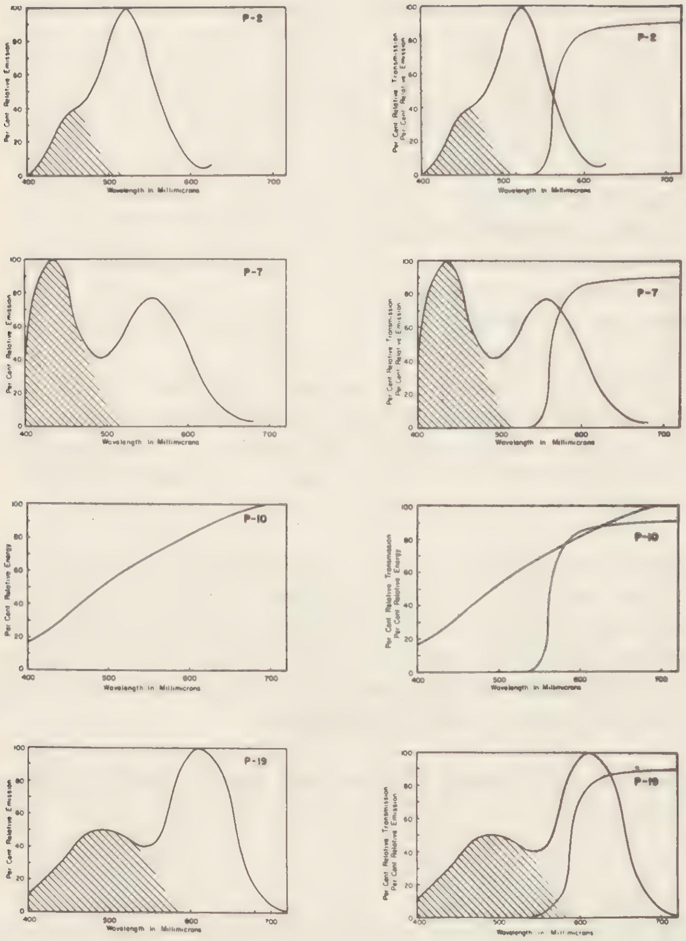

Fig. 2. Spectral Energy Emission Characteristics of Four Phosphors (left-hand graphs) and the Same Phosphors as Modified by Transmission through the Yellow-Orange Filter of the BBB System (first three right-hand graphs) and by the Built-In DuMont CM-1 Filter of the P-19 Phosphor (fourth right-hand graph). The shaded area is the emission of the initial blue excitatory flash of the fluoresence.

The classes of phosphors are the P-2, P-7, P-10, and P-19. In the left-hand column of graphs in Fig. 2 are represented the emission spectra of the 2, 7, and 19 classes. The energy curve of the projection source of the VG-2 relection-type repeater is identified at P-10.

The lighting system will be outlined in terms of the major decisions made in its development.

1. The first decision was the allocation of a band of wavelengths for room illumination. Short wavelengths were selected for the room illumination because of two major advantages: (a) the short wavelengths will excite the largest number of fluorescing colors for use in making visible secondary displays, and (b) for cathode ray tube reading the desirable wavelengths are those wavelengths of the emission spectra of the long persistence phosphors. These are the clear regions, under the curves, of the graphs in the left-hand column of Fig. 2. (c) The shaded sections of these graphs represent the short duration fluorescence of the CRT's. Elimination of these wavelengths improves the visibility of the phosphorescence. This may be done by filtration as represented in the right-hand graphs. Such filtration will also exclude the blue room light from the CRT. (d) Hurvich and Jameson's data (2), from their study of spectral sensitivity of the fovea as a function of chromatic adaptation, indicate that a blue adapting light decreases, to a lesser degree, the visual sensitivity to longer wavelengths than does an adapting light of yellow or red.

2. The second decision was the selection of the lower cut-off for the room illumination. Four hundred millimicrons was used to avoid the deleterious effects of ultra-violet light.

3. The intermediate cut-off between the wavelengths used for ambient illumination and those used for observing the CRT's was the third decision. Five hundred and ten millimicrons represents the shortest wavelength that might be used and still eliminate the blue fluorescence of the P-2 and P-7 classes of phosphors. This allows the least reduction in visibility of these two classes of phosphors through filtration. Five hundred and forty

millimicrons represents the longest wavelength that might be used as room illumination, since room illumination containing longer wavelengths will pass through the built-in CM-1 filter of the P-19 scope and cause phosphorescence. The cut-off at 540 mu was adopted as this provided the least saturated and therefore more preferable ambient illumination. The 140 mu range gave a broad band of wavelengths under which the accommodation difficulties reported by Fincham (1) would be least likely to occur. In addition it is more economical in reaching higher ambient room light intensities.

The above decisions describe the filter characteristics required to effect the desired frequency sharing of the visible spectrum. Adequate filters were found in the cellulose acetate blue and yellow-orange filters used by the Air Force in simulated night flying. The spectral transmission curves of both filters are shown in Fig. 3. The blue filter is used over the illumination source and the yellow-orange filter as scope covers and as lenses for optional operator's goggles.

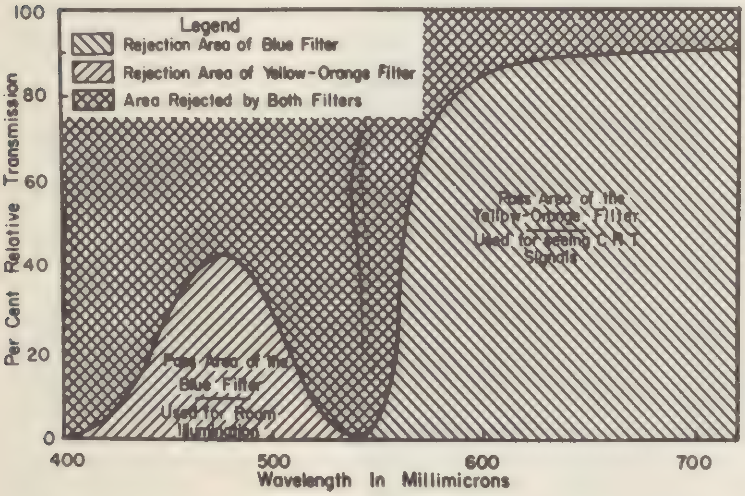

Fig. 3. The Spectral Transmission Characteristics of the Cellulose Acetate Plastic Sheet Filters Used in the Broad-Band Blue Lighting System for RAPCON Centers.

4. The fourth decision was the selection of the most adequate room illumination source. Tungsten and Mercury-vapor were rejected due to the difficulty of filtering which results from their high operating temperatures. Fluorescent sources were selected because they can easily be encased by the filters, and the daylight fluorescent lamp most nearly approximated the hypothetical maximum of a filtered equal-energy source. The transposition of these energy curves to photometric relative values (by reference to the sensitivity data of the human eye) illustrates clearly the advantage of the daylight lamps over the blue fluorescent source.

5. The fifth decision was the choice of an intensity level for the room illumination. The greater the intensity the more adequate the lighting would be for maintenance personnel. A minimal intensity, on the other hand, would assist the scope operators. An intermediate level of 1.3 ft. c. was selected. It is satisfactory for all personnel including the chief controller who must be able to observe operations and also see the radar returns.

These five decisions sketch the theoretical framework of the BBB system and the Wright-Patterson operational installation illustrates its effectiveness. The CRT's appear black with contrasting yellow-orange signals. The maintenance people can make repairs and adjustments during operations, and intra-center activities are facilitated by an illuminated environment. Men can walk into the center from bright outdoor light and see moderately well. The system does not stop here; its flexibility permits these additional advantages: (1) Dark adaptation, through optional use of goggles, gaining for the operator greater visual sensitivity for detection of weak signals. (2) The goggles also eliminate the visibility of specular and diffuse reflections. (3) The use of yellow, orange, and red fluorescent materials to make secondary displays highly visible. Thus, status boards, flight progress strips, maps, controls, and instruments can be made visible to all personnel whether they are wearing goggles or not.

This system has now been in use for approximately two years. We have been able to conduct operational suitability tests as part of the program to evaluate this and other lighting systems.

The first suitability test was an analysis of the visual skills of eight individuals under standard white illumination and under the broad band blue room illumination. The results indicated that visual performance, basic to reading and other general activities, is not adversely affected by the selective illumination of the BBB system.

The second study was the establishment of the quantity of reflectance plus phosphorescence, called "noise", as a function of the amount of diffuse white room light. The function is shown in Fig. 4 as the solid line in the log-log plot. It will be noted that for the same intensity of room illumination the BBB system has 20.16 less "noise" as a product of the room light.

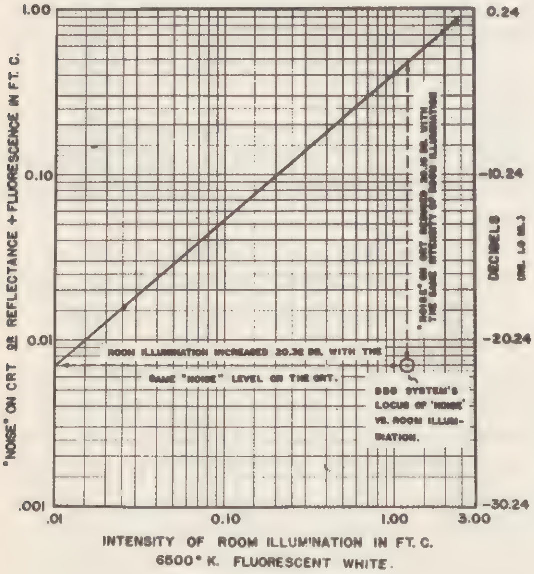

Fig. 4. ''Noise'' on a 12 DP-7 CRT as a Function of the Intensity of White Light Used as Room Illumination. Visual noise is defined as the combined light intensity of reflected light and the phosphorescence of the phosphor of the CRT.

The third measure of operational suitability of the BBB system was a determination of the length of time that the persistence of the phosphor excitation from a radar target is visible under this and alternative systems. A preliminary comparison of this type has been made using simulated targets on two CRT's under conditions of (a) white room light, (b) broad band blue light alone, and (c) BBB light plus the use of goggles. The comparative results provide valuable operational suitability data, but should not be construed as representing either live radar returns or a definitive experiment. The general conditions of this test were as follows: Simulated radar returns of aircraft traveling at speeds of 100, 300, 600 knots on a 40-mile range PPI display, on both a P-7 and P-19 CRT. The room illumination for all conditions had photometric intensity of 1.8 ft.l. The results are to be found in Table 1. Also shown are the gain ratios of the BBB system over white light.

Table 1

The Relative Time in Seconds that a Simulated Radar Return Was Visible Under Three Conditions of Room Illumination

Phosphor Class	White Light	BBB Light	BBB Light Plus Y-O Goggles
P-7	6	66 (11:1)	132 (22:1)
P-19	6	84 (14:1)	217 (36:1)

(Note: A yellow-orange filter covered the P-7 scope for all three tests.)

The fourth study of operational suitability of the BBB was a questionnaire prepared and distributed by Dr. Edgar Chenoweth to 11 controllers and 9 maintenance personnel. This questionnaire was completed by these individuals after the BBB system had been in the operational center for a year. The most frequently mentioned favorable aspects of the BBB system were that (1) it allows maintenance, seeing and moving about during RAPCON operations; (2) it improves visibility of CRT and secondary displays; (3) the use of the goggles adds further target resolution and visibility of trail. Unfavorable comments regarding the system were (1) that difficulty was experienced in using color coding of wires, resistors,

capacitors, etc.; (2) not enough light was provided for all types of maintenance, and (3) the goggles were uncomfortable. It should be emphasized, however, that the basic principle of selective spectral lighting is capable of further improvement. As an illustration, we believe that manufacturers of resistors and electrical wires could use dyes which would fluoresce in different colors under the blue room illumination.

As an illustration of the changes in the appearance of a P-7 CRT as a function of the Broad Band Blue system of lighting a RAPCON Center a photographic illustration is included as Fig. 5.

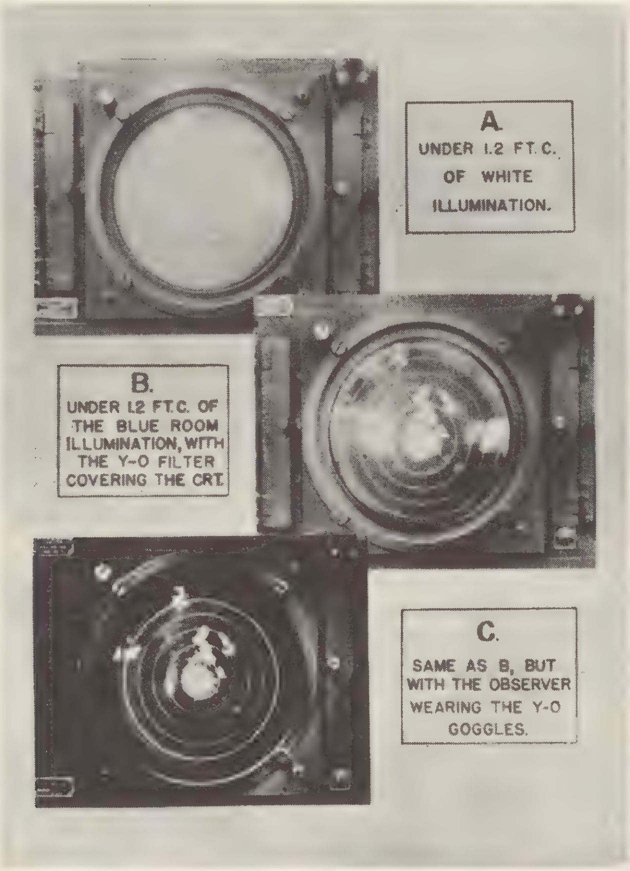

Fig. 5.

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1. Fincham, E. F.: The Accommodation Reflex and Its Stimulus. British Journal of Ophthalmology.

2. Hurvich, L. M., & Jameson, D.: Spectral Sensitivity of the Fovea, II Dependence on Chromatic Adaptation. Journal of Optical Society of America. 1953, 43, 552-559.

Discussion:

Mr. Kraft commented on the research by Fincham, indicating that use of monochromatic light has an influence on the function of accommodation. It is Fincham's hypothesis that the chromatic aberration of the eye is the mechanism by which accommodation is mediated. Mr. Kraft wanted to have some reaction from the Vision Committee as to the importance of this effect. Fincham used steady fixation under instrumental conditions, whereas with the Broad-Band-Blue system the men are operating under circumstances where change of fixation is the rule rather than the exception.

CDR Farnsworth said that he was greatly impressed by the Broad-Band-Blue system.

Mr. Kraft mentioned that the installations on a center as big as this could be done for less than $500.

CDR Farnsworth considered the low cost one of the chief advantages of the system; the target that it is important to see is, of course, the radarscope. It is assumed that everything else in the room is primarily for orientation purposes, and is information which does not require high acuity to interpret it. Therefore, the central stimulus to accommodation is foveal and that is the same region where precise acuity is required. Therefore, no difficulty or incompatibility would be expected because the stimulus to accommodation is the material which requires the greatest acuity.

Mr. Kraft agreed this would be true certainly for those who are watching the radarscope. It is a problem primarily where the maintenance people do not have this type of viewing situation. These people do not see the cathode-ray tubes and Mr. Kraft was concerned particularly about their showing visual malperformance when they are working on radar indicators that are not on or in a section of the room away from other sources of red, yellow and orange light.

CDR Farnsworth said that actually there is not very much reliable information available on the effect of wavelength of light upon acuity. The important thing, as long as you are working under one type of wavelength or one band, whether it is a short band or a broad band, is to exclude any red from the filters so that there is no conflict of accommodation.

Mr. Kraft thanked CDR Farnsworth and said that he was particularly interested in his comments to the effect that there is no data to indicate that using the blue light would be detrimental. Mr. Kraft thought this would mean that the P-7 and the P-2 could be made even more visible. The P-2 is not so critical because it is used on a taxiway radar which does not need long persistence, but the P-7 is used on slower antenna rotations and the long persistence is usable.

A MOVING TARGET OPTICAL PROJECTOR FOR USE IN AIR-TRAFFIC-CONTROL RESEARCH*

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I. PURPOSE

The purpose of this report is to describe an optical projector that has been designed for human-engineering research in air-traffic-control systems. The projector was developed in order (1) to provide a device capable of producing optically a display of position and of other symbolically-coded information necessary for a remotely-controllable air-traffic-control display, and (2) to furnish a versatile projector for use in research studies of different types of displays, for example, studies of the ability of controllers to use auxiliary information about aircraft identity, altitude, etc., when such information is encoded with the basic radar-derived position information.

To meet the general objectives for such an apparatus, more specific requirements for the projector were developed. These requirements were arrived at from a study of the capabilities and shortcomings existing in several other optical air-traffic-control simulators such as the CAA adaptation of the Nava-screen and the simulator developed by the Radio Physics Laboratory in Australia, and from an analysis of the kind of apparatus required in human-engineering research on air-traffic-control. These requirements are outlined below.

1. Target Position and Motion. The projector must provide a means for positioning and maneuvering simulated targets so as to represent the flight track of an aircraft on a one-man radar-type display or on a large projection screen. The motion of the target must be linear at all points on the projection screen.

2. Integrity of Projected Image. The target image projected onto a screen must maintain uniform brightness and sharp focus even when the image is transported to the limits of movement over the projection area.

3. Flexibility of Projected Image. The projector must provide considerable flexibility with respect to what type of symbol may be displayed. It should be possible to project a target image that simulates a radar track with great realism, or takes the form of an arrow, or any other geometric or drawn figure. In addition, it must be possible to surround the target image by a field of focused light in which can be displayed auxiliary information encoded in any form desired (e.g., colors, symbols, digits, letters).

4. Automatic Control. Target motion must be controlled at a remote station by the manipulation of inputs into the drive systems for movement. These inputs should permit horizontal and vertical positioning of the target and also permit the angle of orientation of the image to be rotated through 360 deg.

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5. Compactness. The complete unit which displays one target on a screen must be compact so that it will be possible to stack a group of units side by side and on top of one another. The present unit measures 6 x 6 x 16-5/8 in., so that as many as 36 units can be assembled in a 3-ft. x 3-ft. space. Such an arrangement would provide independent sources for 36 movable targets, each capable of traveling around a 24-in. diameter projection screen at a projection distance as short as 5.4 ft. For a projection screen as large as 10 ft. in diameter the bank of projectors can be located as near as 16.2 ft. from the screen.

II. GENERAL DESCRIPTION

A target (such as a spot of light, arrow, etc.) is produced on a photographic transparency and mounted in the optical projector. The image of this target can be projected to any desired position on a projection screen, and moved precisely by remote control. A photographic view of the projector unit without its case is shown in Figure 1, and the principal details of its construction are indicated schematically in Figures 2, 3, and 4.

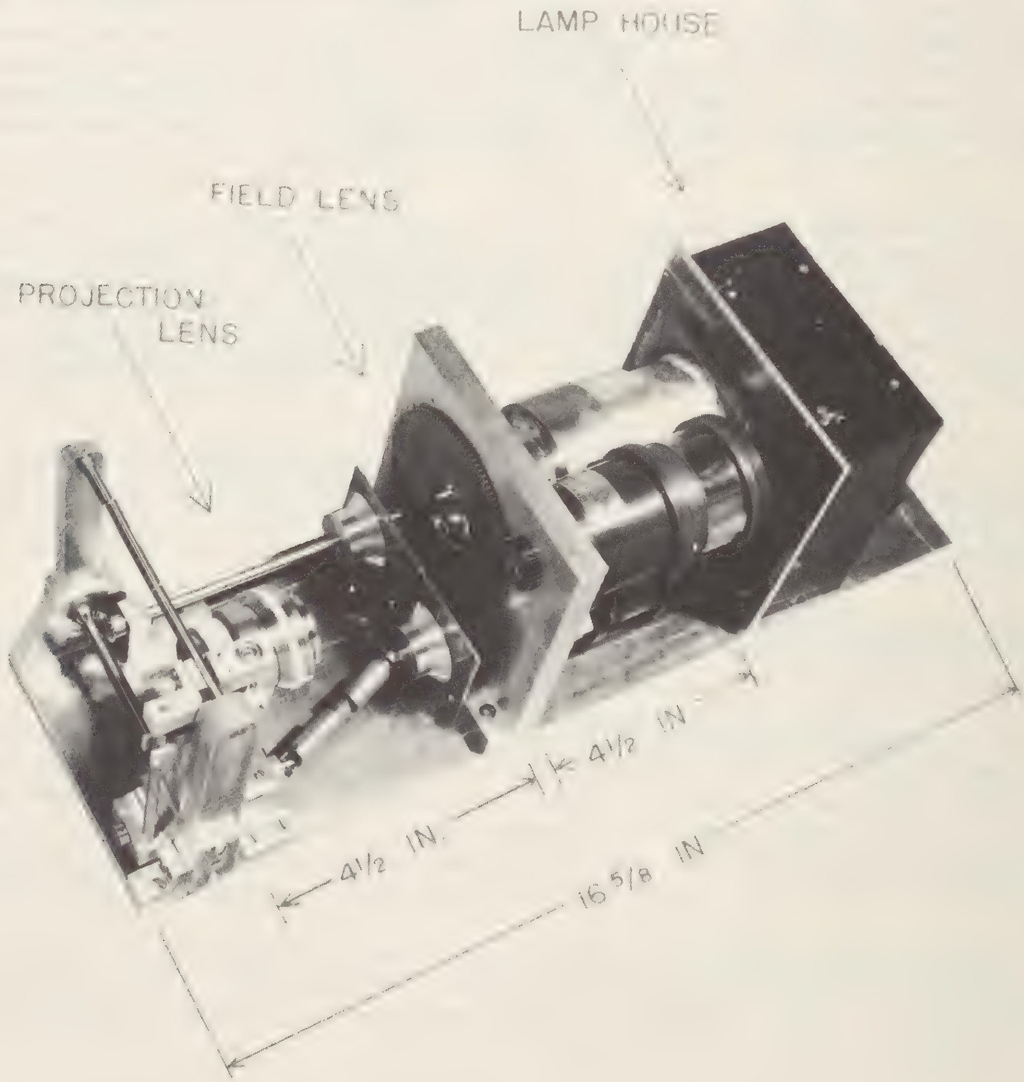

Figure 1. A Photograph of the Projector. A holder for a photographic transparency (not shown) is mounted on the large spur gear surrounding the field lens. A stationary annulus ring is mounted just in front of the photographic transparency.

The Optical System. The optical system is shown in Figure 2. The source is a standard compact filament projection-type bulb of 150 watts. The condenser lenses serve to image the source in the plane of the target. Because this would make the filament of the projection bulb visible on the target, a frosted glass is necessary between the condensers. The sizes and powers of the condenser elements were chosen to give a uniform illumination over the entire area traversed by the projection lens. The field lens is used to obtain a uniform concentration of light in the plane of the projection lens. The projection lens is a photographic enlarging lens with an f/4.5 aperture. It is moved parallel to the film and screen planes, and is itself maintained parallel to these planes.

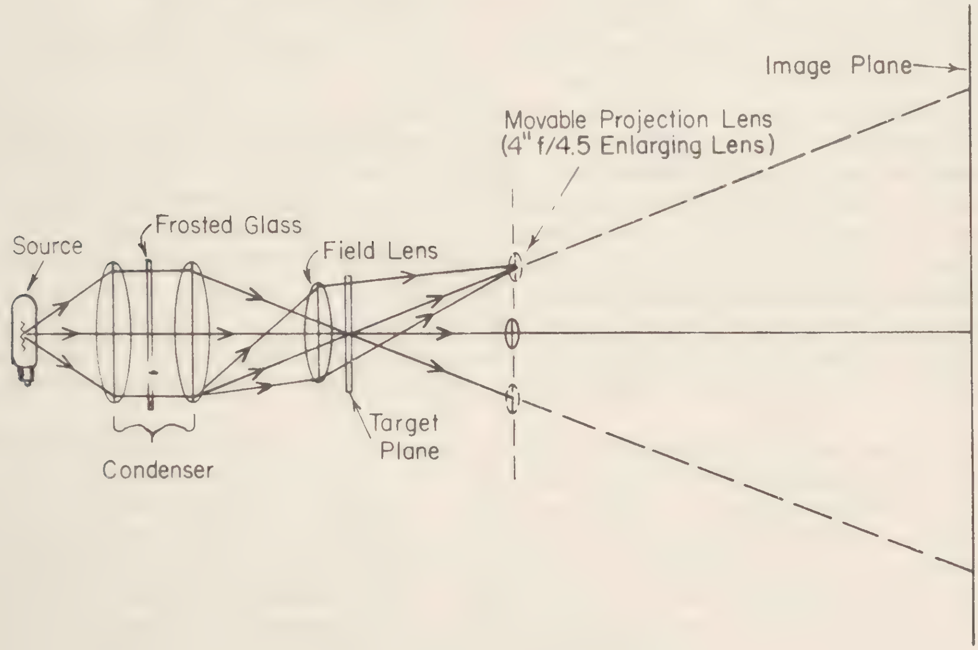

Figure 2. A Diagram of the Optical System Employed in the Projector.

Movement of the Target. The position of the target on the projection screen is controlled by movement of the projector lens in the vertical and lateral dimensions. A rectangular coordinate system is utilized because of its simplicity and ready application to an optical system. Since the image formed by a lens is always located on a straight line through the optical center of the lens and the center of the object, it is possible to move the lens either laterally or vertically and thereby move the image of the target an exactly proportional amount. Modern photographic lenses are designed to give a flat field so that movements of such a lens at right angles to its optical axis will affect neither the focus nor the shape of the image when it is projected on a screen at right angles to the optical axis.

Rotation of the Target. A third dimension of movement has been incorporated along with the lateral and vertical traverse. This dimension is the angle of orientation (inclination or heading) of the target image as it appears on the screen. Target orientation can be made to vary from 0 through 360 deg. as the photographic transparency containing the target is rotated by two selsyn-driven spur gears.

Remote Control of Target Movement. Movement of the target in the three dimensions is in each case controlled by selsyn-driven gear systems. The mechanisms providing lateral and vertical movement are shown schematically in Figure 3. Their actual counterparts are reproduced in Figure 1. The lens is moved horizontally by a worm gear which

is driven by a selsyn reproducing the X component of the simulated aircraft course. The Y component is produced by a similar arrangement except that, as may be seen in Figure 1, the selsyn is linked to the work gear through a pair of miter gears and a differential shaft. The two selsyn motors are actually intended to be followers of another pair of selsyns which can generate signals proportional to the S and Y components of target motion. When the entire system is coupled in this manner, the target image may be driven automatically from a suitable mechanical or electrical course generator with unidirectional movement in the X and Y coordinates; or the X and Y movements may be obtained manually at a remote control station, by supplying hand cranks or wheels to turn the two-drive selsyns. The slave selsyns mounted on the apparatus as shown are 2-1/4 in. in diameter and are 3-5/8 in. long. They gave 4 in.-oz. of torque when operated on 110 v., 60-cycle a.c. current. The lateral and vertical drive systems are geared 1 to 1 from the selsyns, but the two worm gears were turned to a 1 mm. pitch (25.4 threads per in.) so that one complete revolution of the selsyns produced 1 mm. of displacement of the projection lens in either direction.

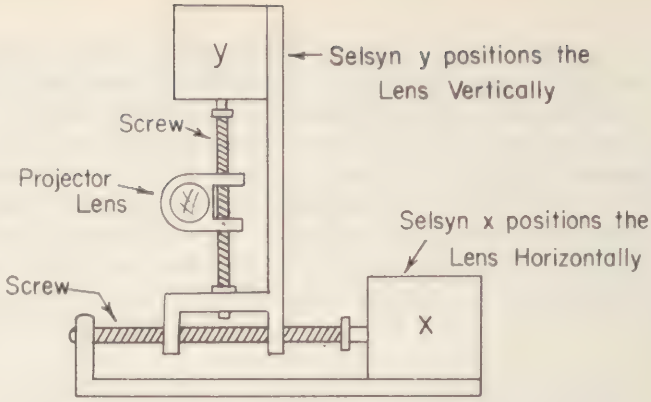

Figure 3. A Schematic Drawing of the Drive Systems Providing Lateral and Vertical Movement of the Projector.

The mechanism which rotates the angle of orientation of the target is represented in Figure 4 and, again, may be found in Figure 1. The selsyn motor, in this case, is linked directly to a spur gear driving a larger one within which is contained the photographic transparency of the target. The gear ratio here is 4 to 1 (the gears are cut 112 to 28) so that one revolution of the selsyn gives 90 deg. of target rotation. Rotation can be obtained in either direction through 360 deg. This system is also designed to be driven either automatically or manually by another selsyn motor at the remote control station.

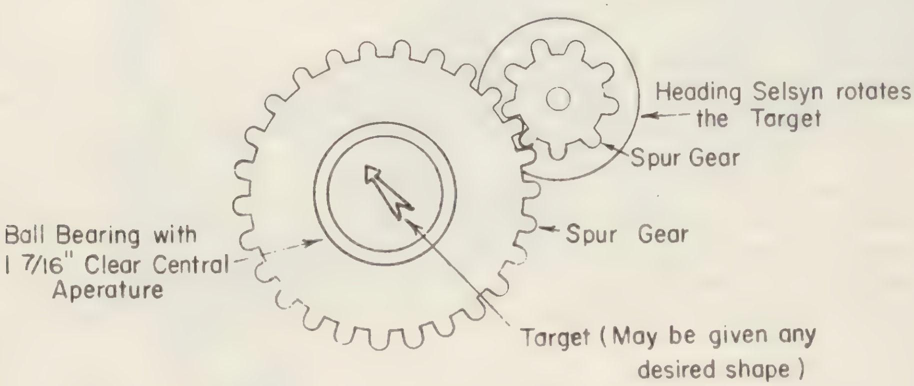

Figure 4. A Schematic Drawing Showing Details of the Gear Arrangement that Rotates the Photographic Transparency which Is Located Immediately in Front of the Field Lens.

Display of Additional Symbolically-Coded Information. An auxiliary stationary target holder may be located just in front of the target plane so that for research purposes additional information can be displayed along with the target. Depending on the actual size of the target on the transparency, the remainder of the 1-7/16 in. aperture may be used. For example, an annulus ring can be placed around the target, and letters, digits, words,

or symbolically-coded information can be displayed on it; or the entire area surrounding the target can be made to appear in different colors and brightnesses with printed or symbolic information again available.

III. APPLICATIONS

Research Uses. The projector can be used to produce the static target displays* which are required to investigate the ability of controllers to predict collisions, estimate the heading that a particular target should take, estimate the point where an aircraft should initiate a turn, or make some other decision regarding various traffic situations. The projector is easily adaptable to the simulation of various amounts of phosphor persistence or history, the simulation of PPI displays of varying sizes, the simulation of radar echoes of various size and sharpness, etc. Moreover, the simulated radar tracks may themselves be symbolically coded to study the interaction of such coding with judgments made from the more conventional radar tracks. Other similar interaction effects may be studied when the tracks are displayed conventionally, but when auxiliary information, symbolic or otherwise, surrounds the target image.

In using the projector for research on other controller functions the experimenter can arrange several projectors to simulate the instantaneous position of several aircraft targets. He can then ask the observer to make a judgment or decision regarding this particular situation, or the observer may be required to adjust a particular target in position or heading so as to indicate an ideal solution for a given traffic-control problem.

At the next level of realistic simulation one or more projectors can be coupled to a suitable course generator in order to study the suitability of different types of displays in a "dynamic" or moving-target situation. The device can be employed, for example, to compare one-man PPI radar-type displays with large projection screens which could be viewed simultaneously by a large number of different controllers.

Potential Use in Actual Traffic Control. At some future time radar-derived target information might become available from some type of storage device capable of supplying electrical voltages corresponding to target position and heading. If it were desired to display such information on a large projection surface, the type projector described here would be readily adaptable to position targets at the appropriate points on the display. Images from the projector could be oriented to indicate each target's heading or the ground track that was being made good. The projected targets could, of course, be driven automatically from the storage device.

The projector could also feasibly be used as a component in a gunnery or other training device.

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*The term ''static target display'' refers to a simulated radar track in which a series of echoes from a moving target, maintained as a number of discrete blips by the phosphor persistence of the tube, are simultaneously displayed. This method gives a simulated display much like what would be obtained if a photograph of a PPI scope showing the persistent traces of moving targets were taken.

AN INVESTIGATION OF "SET" IN THE IDENTIFICATION OF VISUALLY DISTORTED LETTERS AND WORDS

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A large proportion of the human operator's behavior, especially in the process of communication, involves the rapid and accurate interpretation of perceptual stimuli of various kinds. This process of perceiving may vary from a simple glance at a check instrument to such complex tasks as multiple target tracking on a radar scope or multiple aircraft controlling by the tower operator. Thus the messages, displays, signals or other media constituting the perceptual stimuli may vary widely along a number of stimulus dimensions. Furthermore messages or displays may lead to chains or sequences of response, any one of which may themselves vary along numerous dimensions. Such a response chain might begin with location or detection of the stimulus, with subsequent recognition or identification, sometimes in turn followed by other verbal or manual responses, including such complex behavior as "decision-making." Efficiency of operator response in these situations is in part determined by organismic variables, such as proficiency, fatigue, or emotional stress. One such operator variable would appear to be "set" or anticipation of one particular stimulus as opposed to others—i.e., readiness to make one set of responses instead of another.

In the experimental literature of perception there are numerous studies demonstrating that "sets" or expectancies introduced by special instructions or other means, strongly influence the individual's perception of stimulus objects in the environment. By varying the observer's set existent objects have gone undetected, non-existent objects have been reported as perceived, and a wide variety of illusions have been achieved in the recognition or interpretation of stimuli. A survey of the literature reporting investigation of the phenomena of set reveals both a very extensive field of diverse experiments, and a variety of definitions of the concept "set." Furthermore, a large number of terms, such as expectancy, foresight, intention, purpose, attitude, vector, need and preoccupation, have been employed as synonyms for "set." However, it is the contention of the writers that set operated in most of these cases as a process of response restriction or limitation. The apparent fact that different investigators have imposed restriction on the different responses in a behavior series or chain may account for some of the diversity of the experimental findings. If we accept the definition of set in terms of response limitation, it obviously becomes an important variable influencing the probability of response occurrence.

Dr. E. R. Long, Dr. L. Starling Reid, and the speaker have attempted to formulate a general framework within which to plan a program of basic research on the nature of perceptual set. This program has been carried on at the University of Virginia under a research contract for the Aero Medical Laboratory at Wright Air Development Center. The principal assumptions underlying the theoretical framework are the following:

(1) The complex responses called for on the part of the receiving operator in the process of perception are conceived of as chains or sequences of discriminatory responses. Thus at or near the beginning of the response sequence the process might be essentially one of selecting certain stimuli to respond to, including stimulus location, while subsequently in the chain occur the responses involved in identification of the stimulus.

(2) Set is a type of response restriction or limitation operating to increase the probability of the correct discriminatory responses. The fewer the number of response

alternatives in a given stimulus situation, the less will be the likelihood of perceptual error.

(3) Set is differentially effective at different levels of response uncertainty. In other words, we would expect the influence of response limitation to be in part a function of the degree of stimulus ambiguity.

(4) This response restriction is capable of operating at more than one point in the chain of responses, or on more than one of the responses in the sequence.

DESIGN OF EXPERIMENT

	Pre-Stimulus Set			Post-Stimulus Set			Pre-Plus Post-Stimulus Set		
	Level of Diff.			Level of Diff.			Level of Diff.		
No. Alts.	I	II	III	I	II	III	I	II	III
11	3	3	3	3	3	3	3	3	3
8	3	3	3	3	3	3	3	3	3
6	3	3	3	3	3	3	3	3	3
4	3	3	3	3	3	3	3	3	3

Slide 1.

The initial experiment in this program, designed as a preliminary test of the predictions derived from the above assumptions, involved the manipulation of three variables: (1) degree of response restriction (achieved by varying the number of response alternatives); (2) level of response uncertainty (derived from degree of stimulus pattern distortion); and (3) temporal position in the behavioral sequence of the response-limiters or setting cues. This last variable was manipulated experimentally by the introduction of pre-stimulus or post-stimulus cues. By employing both pre- and post-stimulus cuing, variation in number of responses restricted was sought. Stimulus material consisted of distorted letter patterns, assorted into difficulty groups on the basis of frequencies of correct identifications in a previous experiment (without setting cues).

The nature of these letter patterns is illustrated in Slide 2. Note that these letters are formed by square elements, those in the two columns on the left having been composed from a 7 x 5 matrix, while those in the two columns on the right are composed from a 14 x 10 matrix. These letters may be distorted in any of three ways: (1) by omission of elements; (2) by addition of extraneous elements; and (3) by simultaneous omission and addition of elements. The letters in the second row from the top have been slightly distorted by a 10% omission of elements. The letters in the third row illustrate the effect of 30% addition of elements. The letters in the bottom row have been distorted by 60% omission plus addition of elements. These last letters illustrate Difficulty Level III in the present experiment and were correctly identified only about 4% of the time, without benefit of setting information.

Degree of response limitation or "set" was varied by giving the subjects differing numbers of undistorted letters to view (4, 6, 8, or 11), either before or after presentation of the distorted stimulus pattern. Three levels of stimulus distortion or "difficulty" were employed: Level I at 55% correct recognitions in the previous control study; Level II at 22% correct identifications; and Level III at approximately 4% correct. Temporal position of the

setting cues in the over-all response sequence was varied, as indicated above, either before, or after, or both before and after, presentation of the distorted stimulus pattern.

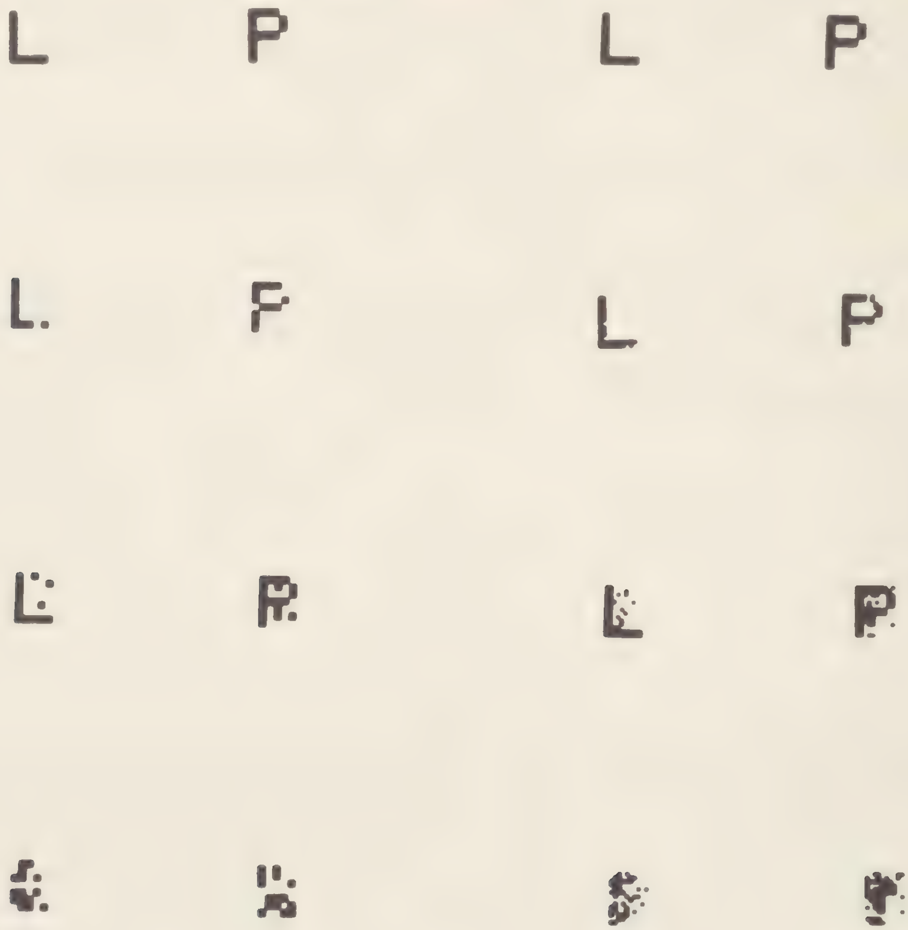


Illustration of Stimulus Letter Patterns

Slide 2.

It can be noted from Slide 1 how manipulation of these variables should test the predictions derived from the four basic assumptions listed earlier: (1) the facilitating effect of response restriction was to be shown both by comparing the results with a limited number of alternatives with those of the previous control study, and also by noting the differential influence of varying numbers of alternatives; (2) the differential effect of "set" at different levels of stimulus difficulty or response uncertainty was to be verified in terms of success of identification as related to degree of stimulus difficulty; (3) the prediction of more than one response in the behavioral sequence, and of set's influence on more than one response in this sequence, was to be tested in differential results springing from temporal position of setting cues, and from increased facilitation derived from pre- plus post-stimulus setting.

One hundred eight subjects were randomly assigned to the 36 cells, 3 subjects to each cell, as shown in Slide 1. Each subject viewed 33 letter patterns. Pre- and post-stimulus viewing time of the undistorted lists of letters was 6.5 seconds. Presentation time of the distorted single-letter patterns comprising the stimuli was 4.8 seconds.

TOTAL NUMBER OF CORRECT IDENTIFICATIONS

	Pre-Stimulus Set				Post-Stimulus Set				Pre-Plus Post-Stimulus Set			
	Level of Difficulty				Level of Difficulty				Level of Difficulty			
No. Alts.	I	II	III	Total	I	II	III	Total	I	II	III	Total
11	61	28	15	104	67	44	26	137	64	44	23	131
8	45	39	12	96	70	51	23	144	67	41	30	138
6	73	59	23	155	68	59	24	151	71	62	40	173
4	68	54	43	165	81	45	55	181	80	54	48	182
Total	247	180	93	520	286	199	128	613	282	201	141	624

Slide 3.

Slide 3 shows the results in terms of frequencies of correct identifications for each of the 36 experimental conditions (total possible correct—99).

The following trends may be noted from the slide:

1. Number of correct recognitions is related to level of difficulty, for all numbers of response alternatives and all temporal positions of the setting cues.

2. Number of correct recognitions is also related to number of response alternatives (and considerably higher than found in the previous control experiment); some reversals may be noted.

3. Post-stimulus setting is more effective than pre-stimulus setting; pre- plus post-stimulus setting is no better than post-stimulus setting alone.

ANALYSIS OF VARIANCE

Source of Variation	S sqs.	df.	Mean Sq.	F
A. Setting Time	197.6	2	98.8	7.6 **
B. No. of Alternatives	673.0	3	224.3	17.3 **
C. Difficulty	2867.7	2	1433.6	110.3 **
A X B	73.8	6	12.3	
A X C	4.3	4	1.1	
B X C	225.7	6	37.6	2.9*
A X B X C	159.4	12	13.3	1.0
Error	934.0	72	13.0	
Total	5135.5	107		

** Significant at the 1% level

* Significant at the 5% level

Slide 4.

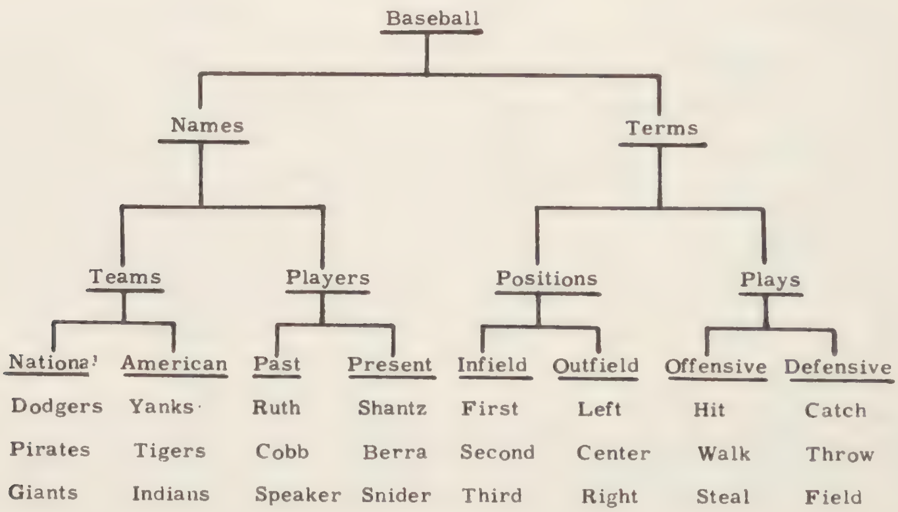
The results of the analysis of variance of the data are shown in Slide 4. Note that all three variables contribute significantly to the total variance, i.e., all significantly influence the number of correct identifications. Note also that the only significant interaction is that between number of response alternatives and level of difficulty of the stimulus patterns.

The results thus clearly substantiate two of the predictions derived from the four basic assumptions underlying the general model, namely, (1) set or response-restriction operates in perception to increase the probability of correct stimulus identification; and (2) set is differentially effective at different levels of response uncertainty. The obtained results do not support the other two assumptions, relating to the existence of, or the restricting of, more than one response in the over-all behavioral sequence involved in perceiving distorted letter stimuli.

More recent experiments at Virginia have sought to extend the usefulness of "set" to situations more nearly approximating those encountered in military operations. Message analysis research in both civilian and military air traffic control operations has revealed the highly structured nature of air communication. The messages are clearly categorized, and usually follow one another in definite sequences. The operators who send and receive these messages are not only highly familiar with the general message population but also enjoy the advantages of contextual setting.

The investigators at the University of Virginia speculated as to whether or not the findings of the earlier experiments would generalize to the highly structured and familiar messages exchanged during communication in air operations. More specifically, it was questioned whether further attempts at response restriction by means of setting cues would be effective in a perceptual situation in which responses were already markedly restricted by reason of familiarity and context. Accordingly a laboratory investigation was designed to answer the following questions: (1) Is the probability of a given identification response increased by progressive restriction of the specific categories in which it occurs within a logically organized word population? (2) Is familiarity with the specific words, apart from knowledge of the word categories, a factor in the effectiveness of this "setting"? (3) Is there a critical point in the degree of response restriction where further restriction fails to aid word identification?

WORD CATEGORY I

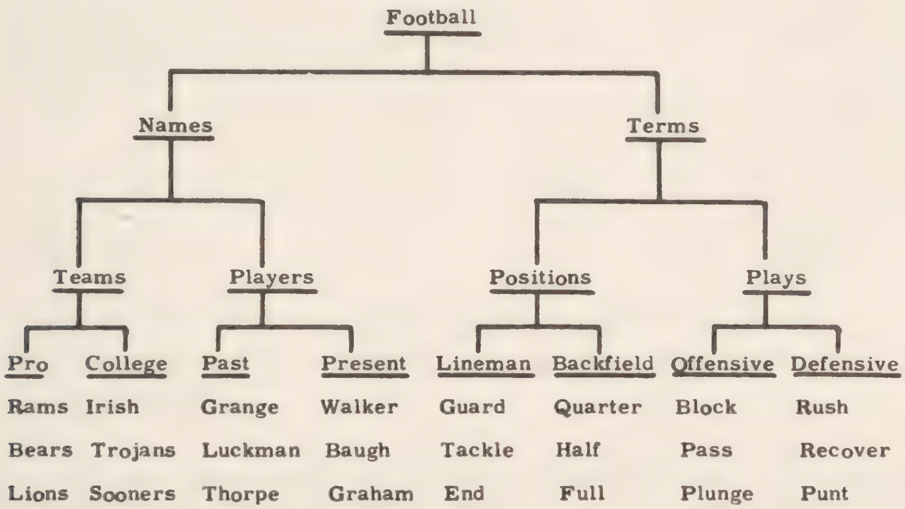


Slide 5.

Ninety male college students served as subjects. There was constructed as a "message" population, a list of 48 words, all related to the general subject of sports. The organization of the 48 words was composed as follows: First there were two broad categories, one relating to baseball, the other to football. Each of these two major categories was then subdivided into successively smaller categories, as shown in Slide 5 for the baseball category.

Note from Slide 5 the two categories of names and terms; then the next four subcategories—teams, players, positions, and plays. Note the final eight smallest categories, with three words each. Slide 6 shows the breakdown for the football category, containing the other 24 words of the list. (Note the parallel structure to that followed in the baseball classification.) Thus the total population of 48 words, was structured into successively smaller sub-groups down to very specific categories of three words each.

WORD CATEGORY II



Slide 6.

The stimuli were prepared for presentation in the following manner: The words were first typed on individual cards, being made of equal length by typing X's where necessary before the first letter, and after the last letter of each word so that all stimulus words contained exactly nine letters. The following is an example: XXGUARDXX. These individual cards were then photographed with the camera misfocused and 35-mm. transparencies were made from the film. During presentation the word stimuli were further distorted by projecting somewhat out of focus. The ambiguity of the resulting stimuli was demonstrated by the fact that identification was reduced to approximately 2% correct under conditions of no setting information, i.e., without category cues.

Prior to the subjects' attempted identification of the words, two types of familiarization were provided. One group was given a sheet on which both the organization of the categories and the stimulus words were printed. The second group was given sheets which contained only the organization of the categories, without the words. Both groups were given a five-minute period during which they studied their respected sheets. At the end of that time they were required to reproduce the material graphically on sheets of paper. Following this test they were given a second five-minute study period, at the end of which time stimulus presentation was begun.

During the course of stimulus presentation, degree of setting was varied by "cuing" the subject with varying numbers of category terms, ranging from one to five. Thus those subjects receiving the lowest degree of setting, saw prior to the stimulus presentation only the one word, Sports. Those receiving the next highest degree of setting saw two words (Sports—Baseball or Sports—Football) depending upon which stimulus word was to be presented. Those subjects having the highest degree of setting saw five successive descriptive or categorizing words, thus—Sports-Football—Name—Team—Pro—the specific combination of cue words again being determined by the particular stimulus word to be viewed.

DESIGN OF EXPERIMENT

Degree of Setting

	I		II		III		IV		V	
Type of Famil	W+O	O	W+O	O	W+O	O	W+O	O	W+O	O
Pre-Stimulus	3	3	3	3	3	3	3	3	3	3
Post-Stimulus	3	3	3	3	3	3	3	3	3	3
Pre-Plus-Post Stimulus	3	3	3	3	3	3	3	3	3	3

W+O--Group Familiar with Words and Organization

O--Group Familiar with Organization Only

Slide 7.

As in the earlier studies, temporal position of the setting cues was a variable: (1) pre-stimulus, (2) post-stimulus, or (3) pre- plus post-stimulus. It was the task of each subject under all conditions to identify each stimulus word by writing it in on a prepared answer sheet. The variables—type of prior familiarization, degree of restriction, and temporal position of cuing, were organized into the factorial design illustrated in Slide 7.

The mean scores (in terms of numbers of correct identifications) for each condition are shown in Slide 8. The over-all effectiveness of the setting cues as an aid to correct recognition is strikingly apparent.

(1) Total score is 16 x 3 = 48; (2) scores increase with greater degree of restriction (I-V); (3) scores are higher for words plus organization than for organization alone; (4) there is no clear effect of temporal position of the setting cue.

An analysis of variance of these data indicates that both degree of setting and type of previous training significantly influenced number of correct identifications. Temporal position of setting (pre-, post-, or pre- plus post-) did not significantly alter the number of correct identifications.

Attention is called to the significant interaction between the degree of setting and the type of familiarization. This interaction affords evidence that accuracy of identification can be increased by progressively reducing the size of the category from which the stimulus word is selected, and furthermore that this increased accuracy is greater when the subjects have been previously familiarized with the specific stimulus words.

MEAN NUMBER OF CORRECT RESPONSES

Degree of Setting

Type of Famil	I W+O	I O	II W+O	II O	III W+O	III O	IV W+O	IV O	V W+O	V O
Pre-Stim	14.0	12.7	18.0	13.3	21.7	15.7	24.3	31.7	42.0	17.0
Post-Stim	19.7	15.0	16.3	13.3	16.7	16.3	30.0	26.0	31.0	12.3
Pre-Plus-Post Stim	19.0	18.7	16.7	12.0	24.0	17.0	37.0	24.3	32.0	25.0

W+O--Group Familiar with Words and Organization

O--Group Familiar with Organization Only

Slide 8.

ANALYSIS OF VARIANCE

Source of Variation	S Sqs.	df	M Sq.	F
A. Degree of Setting	2807.2	4	701.8	13.3**
B. Temp Setting Pos	126.3	2	63.2	1.2
C. Famil Method	846.4	1	846.4	16.0**
A X B	269.8	8	33.7	
A X C	665.7	4	166.4	3.2*
B X C	0.6	2	0.3	
A X B X C	609.3	8	56.2	1.1
Error	3170.0	60	52.8	
Total	8496.3	89		

** Significant at the 1% level

* Significant at the 5% level

Slide 9.

In summary, the results of the second experiment thus contribute added confirmation of the earlier theoretical model as to the nature and effectiveness of "set." This experiment further demonstrates that setting, or response-restriction, may be accomplished by the use of contextual cues rather than by the presentation of response alternatives which was the method followed in the earlier experiment. Finally, these results point to the advantage of cuing or setting the perceiver even when the stimulus population is relatively small and highly organized. Presumably the findings of this investigation have generality to situations involving the perception of distorted word messages where observers are already influenced by contextual setting and familiarity with the messages.

A NEW THEORY OF VISUAL DETECTION*

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University of Michigan

This paper is concerned with the human observer's behavior in detecting light signals in a uniform light background. Detection of these signals depends on information transmitted to cortical centers by way of the visual pathways. An analysis is made of the form of this information, and the types of decisions which can be based on information of this form. Based on this analysis, the expected form of data collected in "yes-no" and "forced-choice" psychophysical experiments is defined, and experiments demonstrating the internal consistency of the theory are presented.

As the theory at first glance appears to be inconsistent with the large quantity of existing data on this subject, it is wise to review the form of this data. The general procedure is to hold signal size, duration, and certain other physical parameters constant, and to observe the way in which the frequency of detection varies as a function of intensity of the light signal. The way in which data of this form are handled implies certain underlying theoretical viewpoints.

In Figure 1 the dotted lines represent the form of the results of hypothetical experiments. Consider first a single dotted line. Any point on the line might represent an experimentally determined point. This point is corrected for chance by application of the usual formula:

$$p = \frac{p' - c}{1 - c} \qquad (1)$$

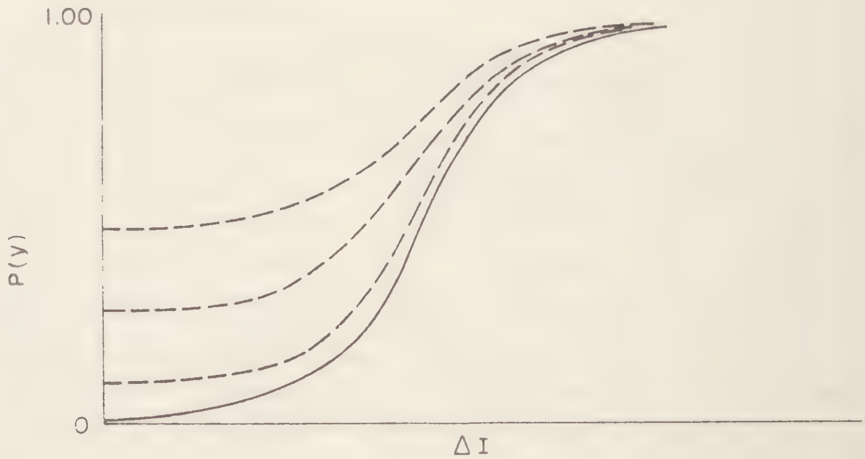

Figure 1. Conventional Seeing Frequency or Betting Curve.

where p' is the observed proportion of positive responses, p is the corrected proportion of positive responses, and c is the intercept of the dotted curve at $\Delta I = 0$.

Justification of this correction depends on the validity of the assumption that a "false-alarm" is a guess, independent of any sensory activity upon which a decision might be based. For this to be the case it is necessary to have a mechanism which triggers when seeing occurs and becomes incapable of discriminating between quantities of neural activity when seeing does not occur. Only under such a system would a guess be equally likely in the absence of seeing for all values of signal intensity. The application of the chance correction to data from both yes-no and forced-choice experiments is consistent with these assumptions.

*This paper is based on work done for the U.S. Army Signal Corps under Contract No. DA-36-039 sc-15358. The experiments reported herein were conducted in the Vision Research Laboratory of the University of Michigan.

The solid curve represents a "true" curve onto which each of the dotted, or experimental, curves can be mapped by using the chance correction and proper estimates of "C." The parameters of the solid curve are assumed to be characteristic of the physiology of the individual's sensory system, independent of psychological control. The assumption carries with it the notion that if some threshold of neural activity is exceeded, phenomenal seeing results.

To infer that the form of the curve representing the frequency of "seeing" is a function of light intensity is the same as the curve representing the frequency of "seeing" as a function of neural activity is to assume a linear relationship between neural activity and light intensity. Efforts to fit seeing frequency curves by normal probability functions suggest a predisposition toward accepting this assumption.

A New Theory of Visual Detection

The theory presented in this paper differs from conventional thinking with respect to these assumptions. First, it is assumed that false-alarm rate and correct detection vary together. Secondly, neural activity is assumed to be a monotone increasing function of light intensity, not necessarily linear. A more specific statement than this is left for experimental determination.

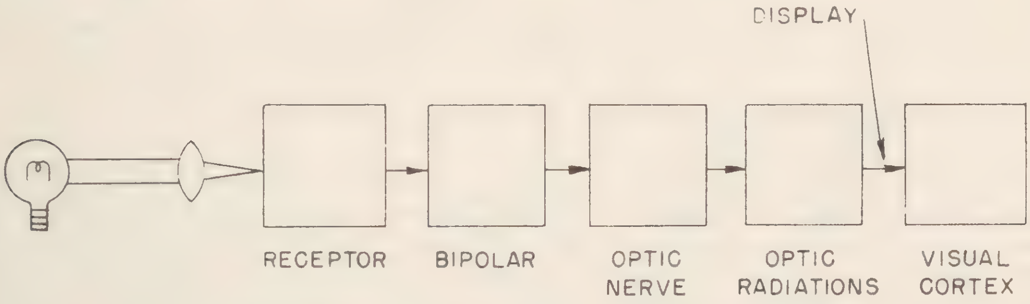

Figure 2. Block Diagram of the Visual Channel.

Figure 2 is a block diagram of the visual pathways showing the major stages of transmission of visual information. All of the stages prior to the cortex are assumed to function only in the transmission of information, presenting to the cortex a representation of the environment. The function of interpreting this information is left to mechanisms at the cortical level.

In this simplified presentation, the displayed information consists of neural impulse activity. In the case under consideration in which a signal is presented at a specified time in a known spatial location, the same restrictions are assumed to exist for the display. Thus, if the observer is asked to state whether a signal exists in location A at time B, he is assumed to consider only that information in the neural display which refers to location A at time B.

A judgment on the existence of a signal is presumably based on a measure of neural activity. There exists a statistical relationship between the measure and signal intensity. That is, the more intense the signal, the greater is the average of the measures resulting. Thus, for any signal there is a universe distribution which is in fact a sampling distribution. It includes all measures which might result if the signal were repeated and measured an infinite number of times. The mean of this universe distribution is associated with the intensity level of the signal. The variance may be associated with other parameters of the signal such as duration or size, but this is beyond the scope of this paper.

Figure 3 shows two probability distributions: N representing the case where noise alone is sampled; that is, no signal exists, and S + N, the case where signal plus noise exists. The mean of N depends on background intensity; the mean of S + N on background plus signal intensity. The variance of N depends on signal parameters, not background

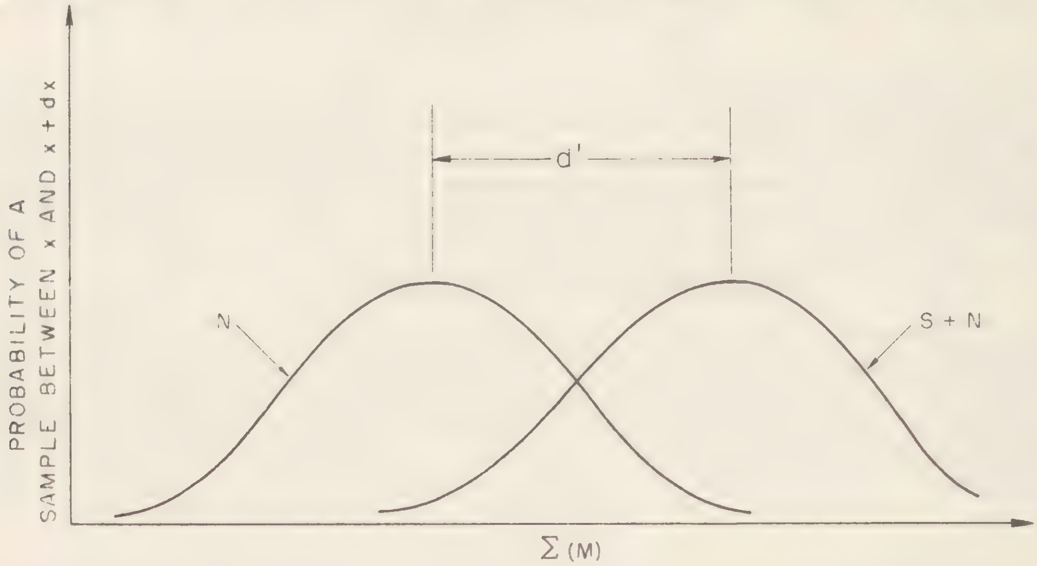

Figure 3. Hypothetical Distributions of Noise and Signal Plus Noise.

parameters, in the case considered here; that is, where the observer knowns "a priori" that if a signal exists, then it will be a particular signal. From the way the diagram is conceptualized, the greater the measure $\Sigma(M)$, the more likely it is that this sample represents a signal. But one can never be sure. Thus, if an observer is asked if a signal exists, he is assumed to base his judgment on the quantity of neural activity. He makes an observation, and then attempts to decide whether this observation is more representative of N or S + N. His task is, in fact, the task of testing a statistical hypothesis.

The ideal behavior, that which makes optimum use of the information available in this task, is defined mathematically by Peterson and Birdsall in "The Theory of Signal Detectability." (2) The mathematics and symbols used are those of Peterson and Birdsall, unless otherwise stated. The first case considered is the yes-no psychophysical experiment in which a signal is presented at a known location during a well-defined interval in time. This corresponds to Peterson and Birdsall's case of the signal known exactly.

For mathematical convenience, it is assumed that the distributions shown in Figure 6 are Gaussian, with variance equal for N and all values of S + N. Experimental results suggest that equal variance is not a true assumption, but that the deviations are not so great that the inconvenience of a more precise assumption is justified for the purpose of this analysis.

It is also assumed that there is a cut-off point such that any measure of neural activity which exceeds that cut-off is in the criterion; that is, any value exceeding cut-off is accepted as representing the existence of a signal, and any value less than the cut-off represents noise alone. Again, for mathematical convenience, the cut-off point is assumed to be well defined and stable. The justification for accepting this convenience is twofold: First, such behavior is statistically optimum, and second, if absolute stability is physically impossible, any lack of definition or random instability throughout an experiment has the same effect mathematically as additional variance in the sampling distributions.

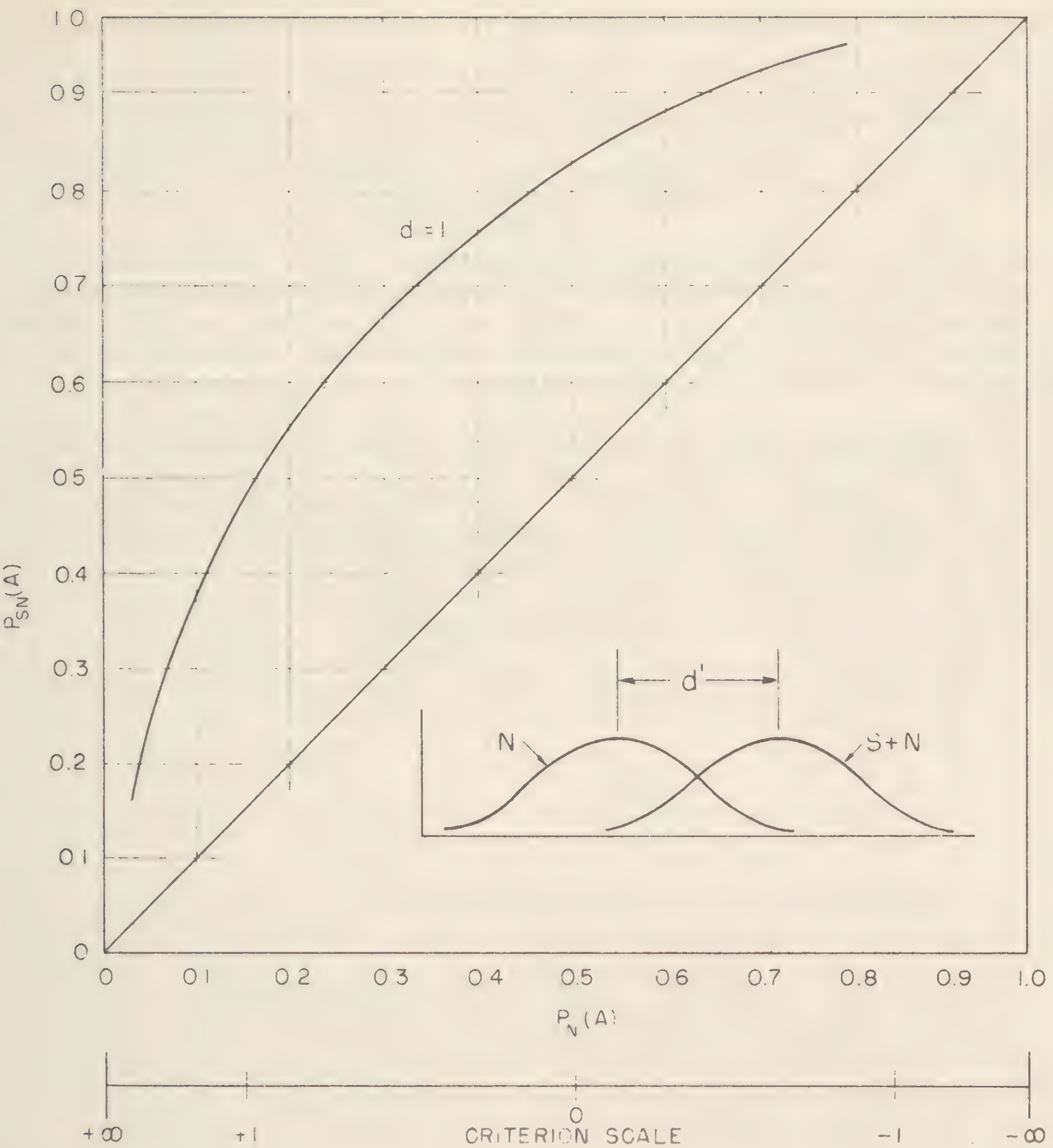

Figure 4. $P_{SN}(A)$ vs. $P_N(A)$. The Criterion Scale Shows the Corresponding Criteria Expressed in Terms of σ_N from M_N.

Now, consider the way in which the placing of the cut-off affects behavior in the case of a given signal. In the lower right-hand corner of Figure 4 the distributions N and S + N are reproduced for a value of d' = 1. The parameter d' is the square root of Peterson and Birdsall's d. The square root of d is more convenient here. d' is the difference between the means of N and S + N in terms of the standard deviation of N. The criterion scale is also calibrated in terms of the standard deviation of N. On the abscissa there is $P_N(A)$, the probability that, if no signal exists, the measure will be in the criterion, and, on the ordinate $P_{SN}(A)$, the probability that if a signal exists the measure will be in the criterion.

If the cut-off is at $-\infty$, all measures are in the criterion: $P_N(A) = P_{SN}(A) = 1$. At minus one standard deviation $P_N(A) = .84$, $P_{SN}(A) = .98$. At zero, $P_N(A) = .5$, $P_{SN}(A) = .84$. At plus one $P_N(A) = .16$ and $P_{SN}(A) = .5$; and for plus ∞ $P_N(A) = P_{SN}(A) = 0$. Thus, for d' = 1 this is the curve showing possible detections for each false-alarm rate. The

curve represents the best that can be done with the information available, and the mirror image is the curve of worst possible behaviors.

The maximum behavior in any given experiment is a point on this curve at which the slope is β where

$$\beta = \frac{1 - P(SN)}{P(SN)} \; \frac{(V_{N \cdot CA} + K_{N \cdot A})}{(V_{SN \cdot A} + K_{SN \cdot CA})} \tag{2}$$

P(SN) is the "a priori" probability that the signal exists, $V_{N \cdot CA}$ is the value of a correct rejection, $K_{N \cdot A}$ the cost of a false-alarm, $V_{SN \cdot A}$ the value of a correct detection, and $K_{SN \cdot CA}$ is the cost of a miss. Thus, as P(SN) or $V_{SN \cdot A}$ increase, or $K_{N \cdot A}$ decreases, β becomes smaller and it is worthwhile to accept a higher false-alarm rate in the interest of achieving a greater percentage of correct decisions.

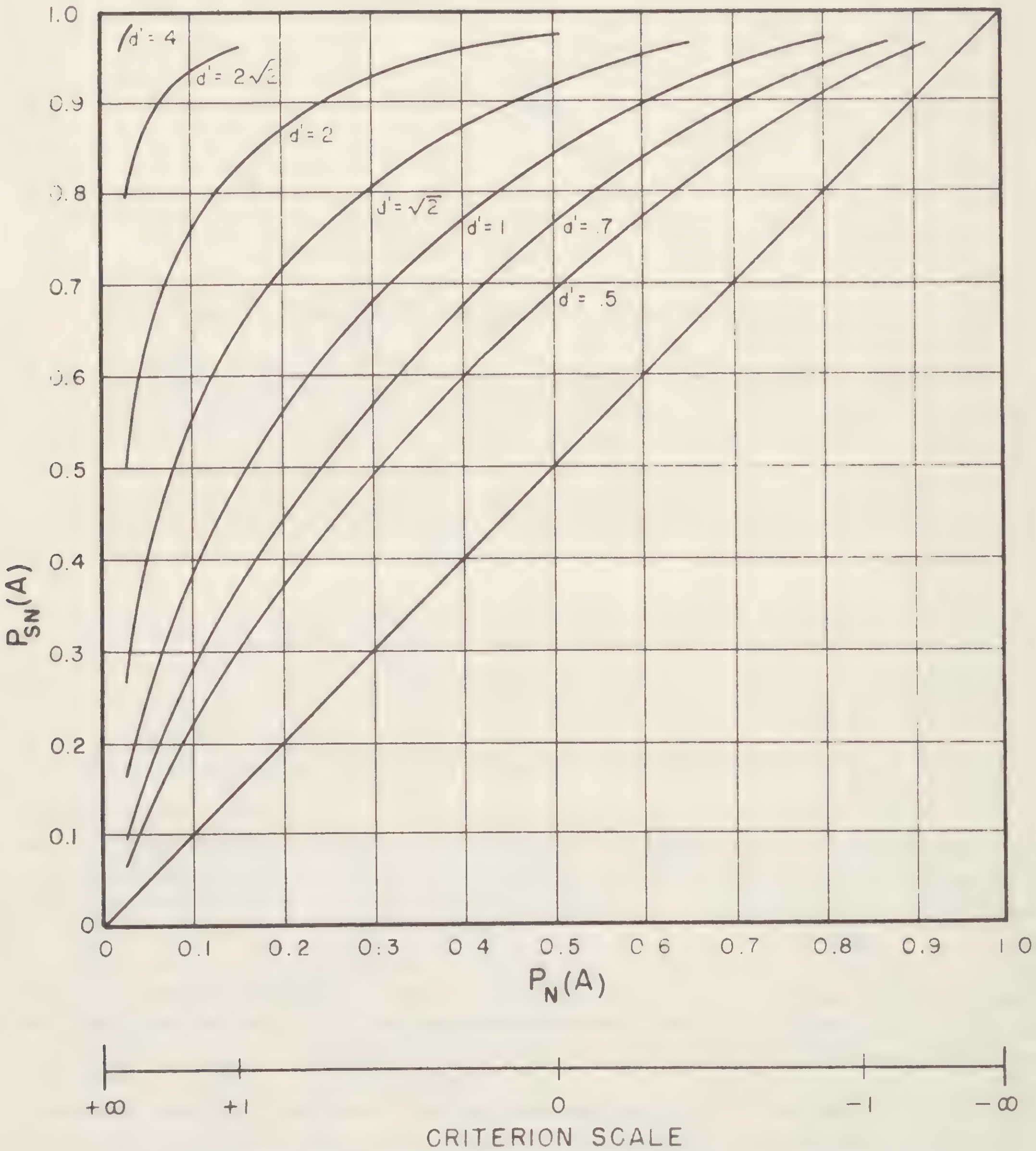

Figure 5. Signal Detector Curves. $P_N(A)$ vs. $P_{SN}(A)$. The Criterion Scale Shows the Corresponding Criteria Expressed in Terms of σ_N from M_N.

Figure 5 shows a family of curves of $P_{SN}(A)$ vs. $P_N(A)$ with d' as a parameter. For values of d' greater than 4, detection is very good. This is to be compared with the predictions of the conventional theory shown in Figure 6 with $P_N(A)$ assumed to represent guesses. For each value of d' it is assumed that there is a true value of $P_{SN}(A)$ either for $P_N(A) = 0$ or for some very small value. The chance correction should transform each of these to horizontal lines.

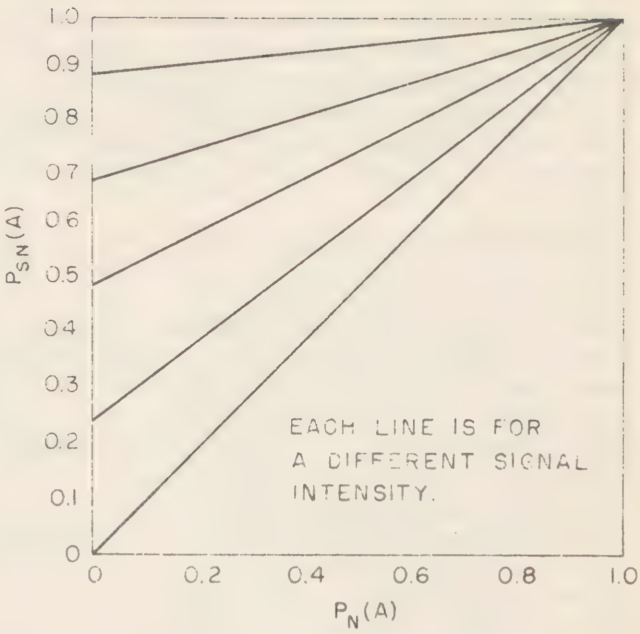

Figure 6. $P_{SN}(A)$ vs. $P_N(A)$ as a Function of d' Assuming the Guessing Hypothesis.

Another way of comparing the predictions of this theory with those of conventional theory is to construct the so-called betting curves, or curves showing the predicted shape of the psychophysical function. These are shown in Figure 7, where P(A), the probability of acceptance, is plotted as a function of d'. These curves will not correct into the same curve by the application of the chance correction. The shift is horizontal rather than vertical. The dotted portions of the curve show that we are dealing with only a part of the curve, and thus, in the terms of this theory, it is improper to apply a normalizing procedure such as the chance-correction formula to that part of the curve.

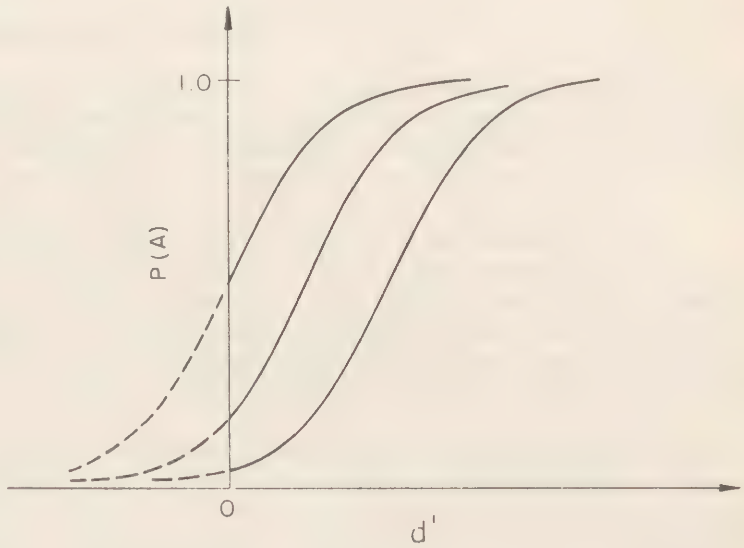

Figure 7. P(A) as a Function of d' Assuming the Theory.

In the forced-choice psychophysical experiment, maximum behavior is defined in a different way. In the general forced-choice experiment, the observer knows that the signal will occur in one of N intervals, and he is forced to choose in which of these intervals it occurs. The information upon which his decision is based is contained in the same display as in the case of the yes-no experiment, and, presumably, the value of d' for any given light intensity must be the same. While the solution of this problem is not contained in "The Theory of Signal Detectability," Peterson and Birdsall have assisted greatly in determining this solution. The probability that a correct answer P(C) will result for a given value of d' is the probability that one sample from the S + N distribution is greater than the greatest of N - 1 samples from the distribution of noise alone. The case in which four intervals are used is the basis for Figure 8. This figure shows the probability of one sample from S + N being greater than the greatest of three from N. For a given value of d' this is

$$P(C) = \int_{x=-\infty}^{+\infty} F(X)^3 g(x)dx \tag{3}$$

where F(x) is the area of N and g(x) is the ordinate of S + N. In Figure 8 P(C), as determined by this integration, is plotted as a function of d' for the equal variance case.

Criterion of Internal Consistency

These two sets of predictions are for the standard experimental situations. They are based on the same neurological parameters. Thus, if the parameters, that is, d''s, are estimated from one of the experiments, these estimates should furnish a basis for predicting the data for the other experiment if the theory is internally consistent. An equivalent criterion of internal consistency is for both experiments to yield the same estimates of d'.

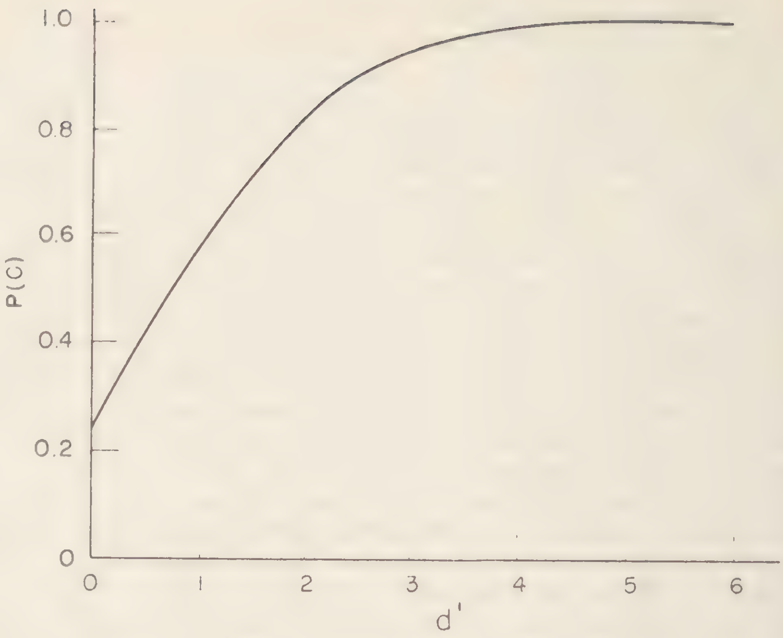

Figure 8. P(C) as a Function of d'—A Theoretical Curve.

Experimental Design

Experiments were conducted to test this internal consistency, using three Michigan sophomores as observers. All of the experiments employed a circular target 30 minutes in diameter, 1/100 second in duration, on a ten foot-lambert background. Details of the experimental procedure and the laboratory have been published by Blackwell (1).

The observers were trained in the temporal forced-choice experiment. The signal appeared in a known location at one of four specified times, and the observers were forced to choose the time at which they thought the signal occurred. Five light intensity increments were used here, with fifty observations per point per experimental session. The last two of these sessions were the test session so that each forced-choice point in the analysis is based on 100 experimental observations.

Following the forced-choice experiments, there was a series of yes-no experiments under the same experimental conditions, except that only four light intensity increments were used. These were the same as the four greatest intensities used in the forced-choice experiments, reduced by adding a .1 fixed filter. In the first four of these sessions, two values of "a priori" probabilities, P(SN) equal to .8 and .4, were used. The observers were informed of the value of P(SN) before each experimental session. No values or costs were incorporated in these four sessions, which were excluded from the analysis as practice sessions.

The test experiments consisted of twelve sessions in each of which all of the information necessary for the calculation of a β (the best possible decision level) was furnished the observers. While they did not know the formal calculation of β, they knew the direction of cut-off change indicated by a change in any of these factors. The values and costs were made real to the observers, for they were actually paid off in cash. It was possible for them to earn as much as two dollars extra in a single experimental session as a result of this pay-off.

The first four sessions each carried the same value of β as P(SN) = .8 and the same pay-off was maintained. A high value of $P_N(A)$, or false-alarm rate, resulted. In the next four sessions with P(SN) held at .8, $K_{N.A}$ and $V_{N.CA}$ were gradually increased from session to session (not within sessions) until $P_N(A)$ dropped to a low value. Then P(SN) was dropped to .4, K_{NA} and $V_{N \cdot CA}$ were reduced so that for the thirteenth session $P_N(A)$ stayed low. The last three sessions successively involved increases in $V_{S \cdot NA}$ and $K_{SN \cdot CA}$ again forcing $P_N(A)$ toward a higher value.

Results

Figures 9 and 10 show scatter diagrams of $P_{SN}(A)$ vs. $P_N(A)$ for a particular intensity of signal and for a single observer. These scatter diagrams can be used to estimate d'. In Figure 9 the estimate of d' is .7. In Figure 10, the estimate of d' is 1.3. Each d' estimated in this way is based on 560 observations. A procedure similar to this was used for the d''s for each of four signals for each of the four observers.

In the forced-choice experiment the estimates of d' are made by entering our forced-choice curve (Figure 8) using the observed percentage correct as an estimate of P(C).

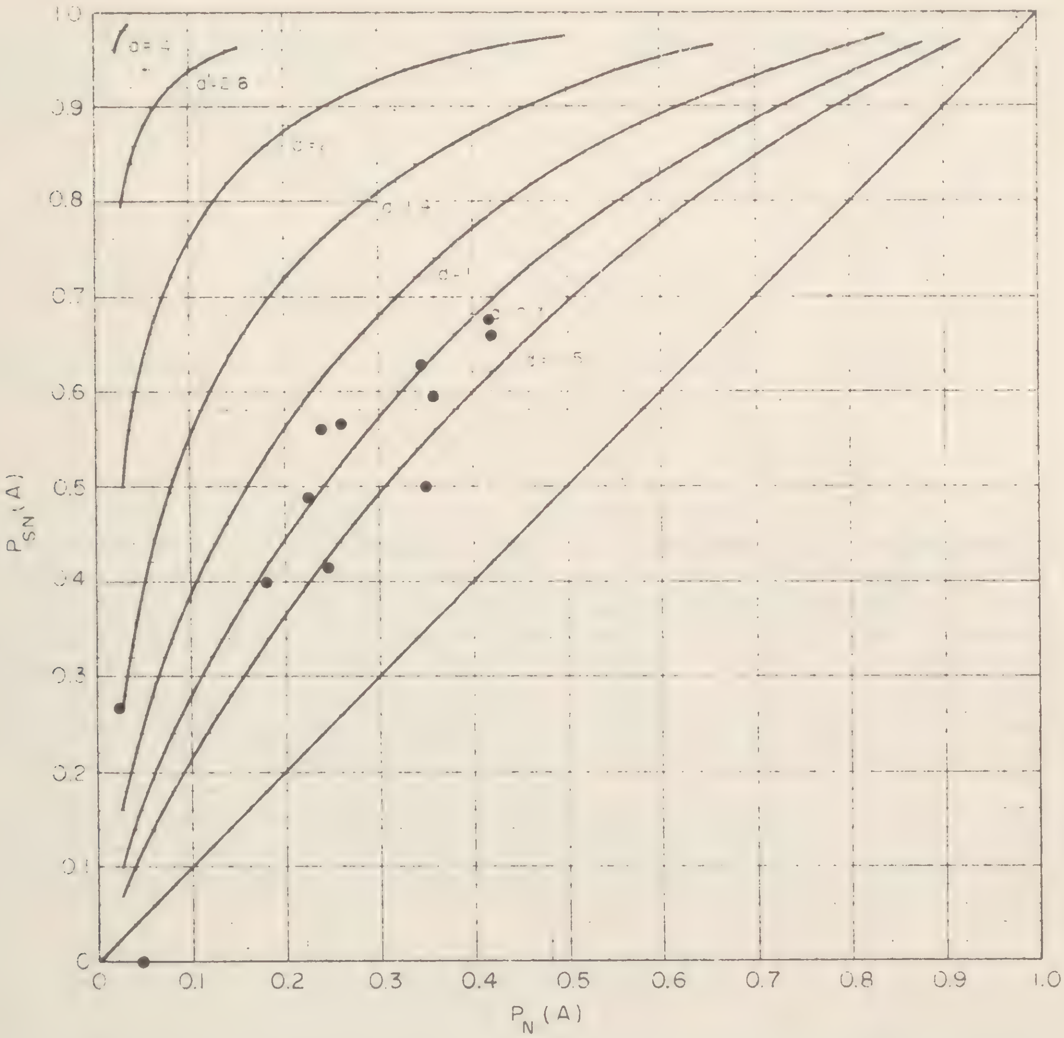

Figure 9.

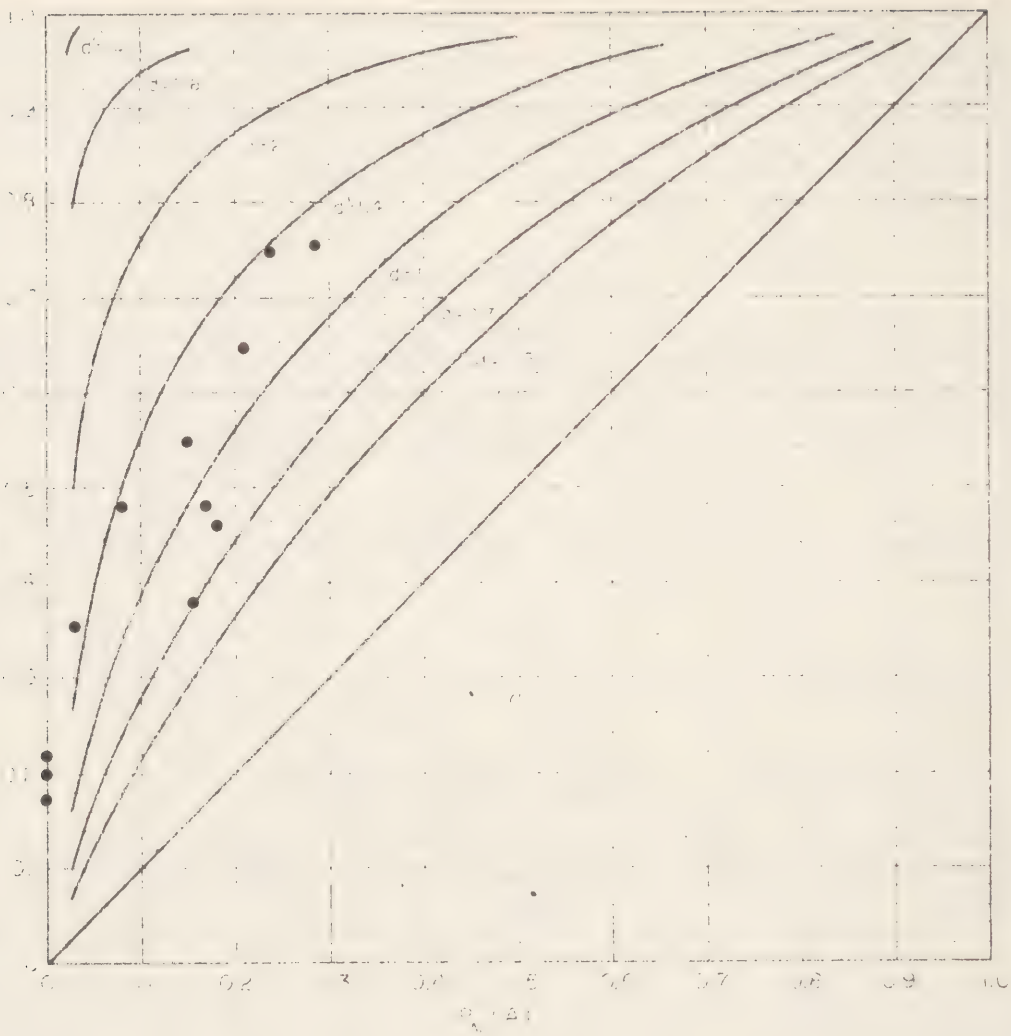

Figure 10.

Figure 11 shows log d' as a function of log signal intensity for the first observer, the estimates of d' being from both forced-choice and yes-no experiments. In general the agreement is good. The deviation of the forced-choice point at the top can be explained on the basis of inadequate experimental data for the determination of the high probability involved. The deviation of the low point is unexplained. Figure 12 is the same plot for the second observer, showing about the same picture. Figure 13 is for the third observer, showing not quite as good a fit, but nevertheless satisfactory for psychological experiments. For this observer, the lowest point for forced-choice is off the graph to the right of the line.

Figures 14, 15, and 16 show the predictions for forced-choice data (when yes-no data are used to estimate d') for the three observers. Note that the lowest point is on the curve in both of the first two cases, suggesting that the deviation which appeared on the curves in Figures 11, 12, and 13 is not significant.

Discussion

The results support internal consistency. The theory also turns out to be consistent with the vast amount of data in the literature, for, when the d' vs. ΔI function for any one of the observers is used to predict probability of detection as a function of ΔI in terms of

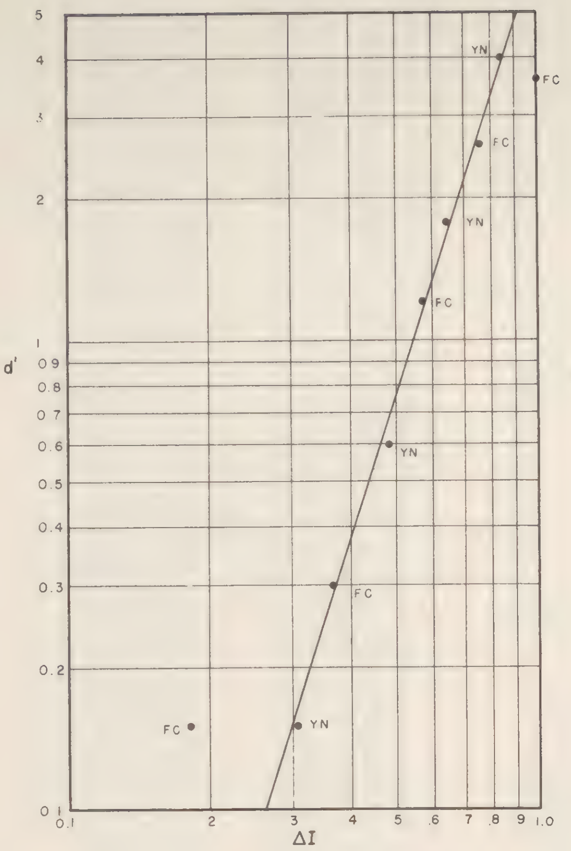

Figure 11. Log d' vs. Log ΔI for Observer 1.

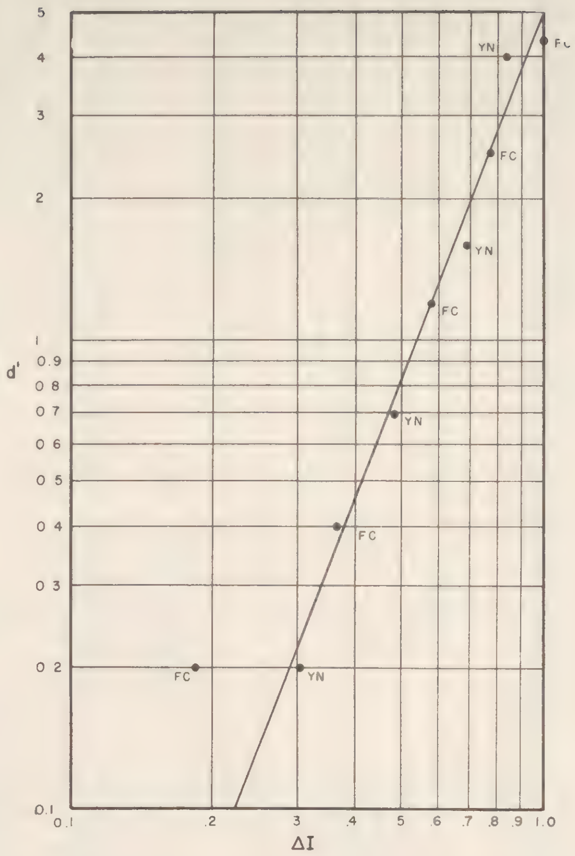

Figure 12. Log d' vs. Log ΔI for Observer 2.

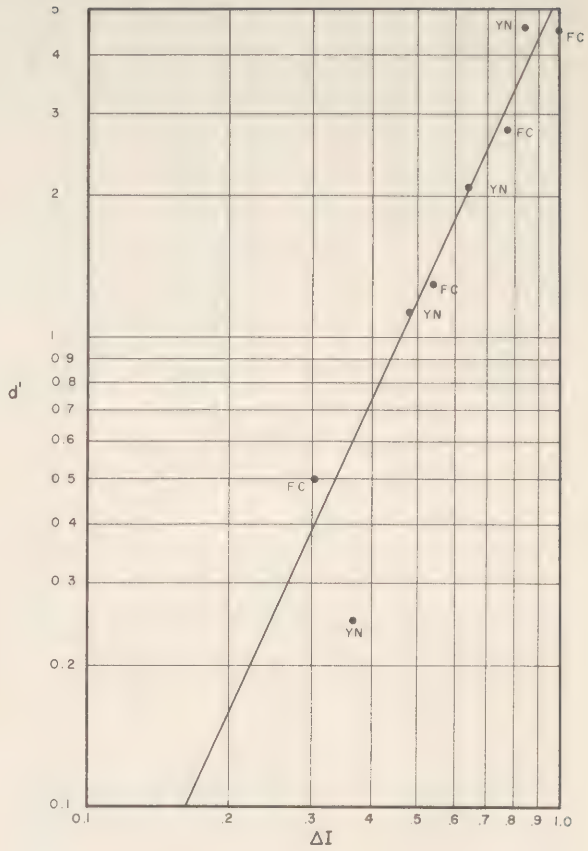

Figure 13. Log d' vs. Log ΔI for Observer 3.

this theory, the result closely approximates the type of curve frequently reported. Shapes of curves thus furnish no basis for selecting between the two theories and a decision must rest on the other arguments.

According to conventional theory, application of the chance correction should yield corrected values of $P_{SN}(A)$ which are independent of $P_N(A)$, or should yield corrected thresholds in the conventional sense which are independent of $P_N(A)$. Rank-order correlations for the three observers between $P_N(A)$ and corrected thresholds (.30, .71, .67) are highly significant; the combined $p << .001$. This is a result consistent with theory presented here.

Another method of comparison is to fit the scatter diagrams (Figures 9 and 10) by straight lines. According to the independence theory, these straight lines should intercept the point (1.00, 1.00). Sampling error would be expected to send some of the lines to either side of this point. There are twelve of these scatter diagrams, and all twelve of these lines intersect the line $P_{SN}(A) = 1.00$ at values of $P_N(A)$ between 0 and 1.00 in an order which would be predicted if these lines were arcs of the curves $P_{SN}(A)$ vs. $P_N(A)$ as defined by the theory of signal detectability.

Figure 14. Prediction of Forced-Choice Data from Yes-No Data for Observer 1.

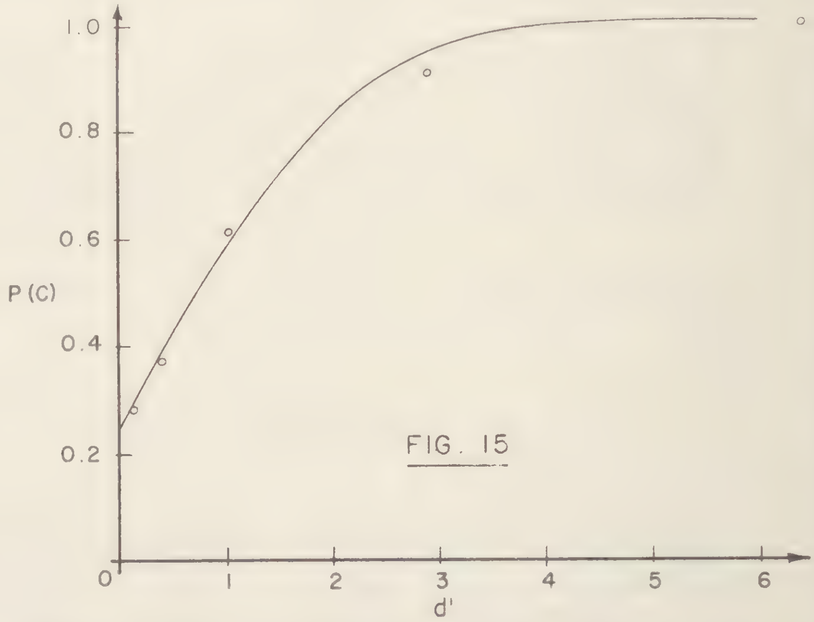

Figure 15. Prediction of Forced-Choice Data from Yes-No Data for Observer 2.

Two additional sessions were run in which the observers were permitted three categories of response (yes, no, and doubtful), in which the observers were told to be sure of being correct if they responded either yes or no. Again two "a priori" probabilities (.8 and .4) were employed, and again $P_N(A)$ was correlated with P(SN). The observers, interviewed after these sessions, reported that their "yes" responses were based on "phenomenal" seeing.

This does not mean that the observers were abnormal because they hallucinated. It suggests, on the other hand, that phenomenal seeing develops through experience, and is subject to change with experience. Psychological as well as physiological factors are involved. Psychological "set" is a function of β, and after experience with a given set one begins to see, or not to see, rather automatically. Change the set, and the level of seeing

changes. The experiments reported here were such that the observers learned to adjust rapidly to different sets.

Conclusions

The following conclusions are advanced:

1) The conventional concept of a threshold, or a threshold region, needs re-evaluating in the light of this theory.

2) The guessing hypothesis is rejected on the basis of statistical tests.

3) Change in neural activity is a power function of change in light intensity.

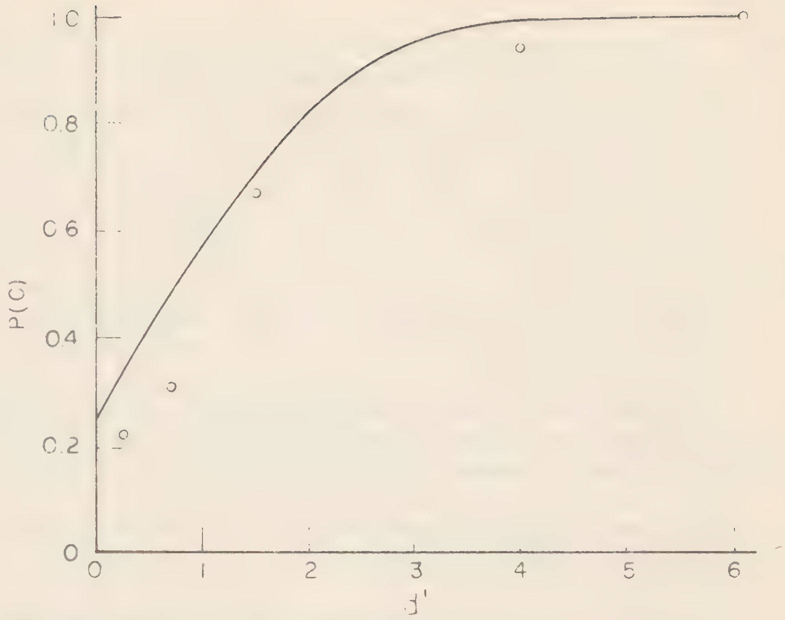

Figure 16. Prediction of Forced-Choice Data from Yes-No Data for Observer 3.

4) The mathematical model of signal detection is applicable to the problems of visual detection.

5) The criterion of seeing depends on psychological as well as physiological factors. In these experiments the observers tended to use optimum criteria.

6) The experimental data support the logical connection between forced-choice and yes-no techniques developed by the theory.

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Discussion:

Dr. Blackwell commended Mr. Tanner on a most interesting presentation and discussed the implications of this research for practical military problems. The research is relevant, for instance, to the attitude an observer should adopt toward false alarms; shall this be one in which there will be few false alarms, or one in which there will be many false alarms? Dr. Blackwell commented that Mr. Tanner's results suggest very clearly that if one forces his subjects to adopt a strict criterion with regard to not making false positives, information is lost which cannot be recovered. Putting it another way, detection probabilities are decreased in a way which cannot be explained merely on the basis of chance. This has real practical value. If we do as most military commanders presumably do, that is, emphasize to observers that they not make false positives, then there will be a definite loss of information which will result in targets not being detected which could otherwise have been detected. This

is complicated by the fact that it is necessary to know what the theory of detection is to know what to do in a practical military situation when we have only one response to go by. A situation occurs, the observer responds "I see a target". Do we take this seriously and act, and if we do act what is the likelihood we will have taken our action in vain? Obviously, to decide what attitude should be adopted, one must decide the value of false positive versus the value of misses, and the way in which these two kinds of things are related.

Dr. Blackwell said Mr. Tanner has presented one theory of these relations, which if shown to be true, would allow for building computers which could be used in military situations to extract the maximum information from responses made by military observers. Actually, for most purposes it is impossible for the experimental data to differentiate between the theory that has been presented and the more classical theory in which one assumes that either in forced-choice detections or in simple yes-no detections the chance principle applies.

Dr. Hulburt asked how much is lost when wrong guesses are not used; that is, how much is lost by forcing a yes?

Mr. Tanner stated that Dr. Hulburt's question has no single answer, because if the false positives are eliminated it is impossible to know where one is operating. It is necessary to force a few false positives to find out where one is operating and where the cut-off point is.

Dr. Blackwell suggested it might be answered another way. The threshold goes up about 30% if subjects are not allowed to use false positives, and perhaps more when information about the target is lacking.

ON THE SCOTOPIC AND RELATED VISUAL FUNCTIONS

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I

In common technical parlance "the scotopic visual function" has been related to rod-visual performance. One is accustomed to viewing, for example, displays of normal human visual functioning which, as in dark-adaptation threshold data, for instance, exhibit the separation of presumably 'cone' photopic function from that attributed to rods. The data of flicker-recognition show unmistakably, however (1), that interactions can and do occur between the two categories of visual effects. And the same kind of thing has been demonstrated during dark-adaptation, particularly by use of a test-image subdivided into stripes (1). The discussion of visual theory has been altogether too prone to forget that visual capacity is definitely a multi-variate affair; workable tests of it have, rather inevitably, striven for a simplicity which in fact does not exist.

I shall discuss here some of the now quite extensive data demonstrating that simplicity of the scotopic, "rod-visual" function is illusory. Recognition of this fact can have a number of consequences. The actual experiments also impinge on various related problems. I shall refer, not at all exhaustively, to three points only: (1) the shape of the fundamental scotopic visual function; (2) the matter of peripheral 'cone' thresholds; (3) "photosensitization" by red light.

The investigation to which this report is a footnote has been supported chiefly through an ONR contract; grateful acknowledgment is made. The work is "unclassified"; certain of its consequences are classified, and these I do not discuss. The primary purpose has been the systematic study of the effects of very short flashes of light (2). Other topics, such as the present, have required examination for purposes of clarification.

II

The experiments under discussion have employed the method of "incremental thresholds." In this procedure (3) a small test-image, of controlled intensity, is briefly presented superimposed upon a standing field, of known luminance, which has been adapted to. By suitable processes a seeing-frequency function is obtained at each of an adequate number of background brightnesses. The large labor of this procedure has been measurably reduced by procedural and recording methods which I do not now describe.

This general approach has a number of special advantages. It permits in a natural way the inclusion of the case in which background illumination I_1 is zero; there is no real restriction on the use of the heterochromatic case, in which I_1 and test illumination ΔI are not of the same λ; and study of the properties of light-adaptation is simple. The ψ (S) data encountered are without exception log-Gaussian in form (4).

At fovea, Stiles (5) claimed that the ΔI - I_1 incremental threshold contour (heterochromatic) exhibited a cusp in each case; from these data he computed λ-primary sensitivity curves. Proper use of ψ (S) has demonstrated (6), (a) that these cusps are illusory, and (b) just how Stiles arrived at his results; these can be duplicated, but are without direct analytical significance.

With excitation outside the fovea the story is more complex. In a large number of tests, with several observers, several exposure-times of test-image, several oxygen concentrations in respiration, for homochromatic and heterochromatic situations, the following has uniformly been observed:

(i) the presumptively 'cone,' photopic, function is unbroken; as at fovea;

(ii) the scotopic function is never simplex, but is duplex;

(iii) if I_1 levels are closely enough spaced, zones of "interaction" are demonstrated.

The discontinuities exhibited in graphs of median $\log \Delta I$ (τ') as function of $\log I_1$ are thoroughly substantiated by the behavior of $\sigma_{\log \Delta I}$ from $\psi(S)$. This behavior directly supports the conclusion that the over-all visual performance contour, as excited in retinal periphery, is not fundamentally duplex, but is at least triplex, --the scotopic excitability contour being itself composed of two zones, in each of which the $\sigma_{\log \Delta I}$ vs. I_1 pattern seen at fovea is essentially reproduced.

III

This does not necessarily mean that there are "two kinds of rods." This particular suggestion has in fact been offered by students of the visual functions of color blinds (7), judged entirely cone-deficient but exhibiting duplex visual response-contours. After all, however, one does not see with the retina. It could mean that, over different levels of light-adaptation, there are two scotopic types of retinal "collector" neurons; or it could mean something else.

At any rate, this evidence for complexity of the "rod" excitability contour does not stand alone. Certain features of the 'fine structure' of the ordinary scotopic dark-adaptation contour may also be relevant. (Recall that Hecht's initial "bimolecular isotherm" for dark-adaptation was passed through manifestly 'broken' data (8). The point here is that closer scrutiny, employing varied methods, can reveal types of complexity at first glossed over (9).

IV

Let it be noted that in every instance each section of the tripartite excitability function responds to quantitative formulation in terms of the conception that $1/\Delta \bar{I}$, taken as $I/\Delta I'_{50}$, as a measure of median excitability, is a declining Gaussian in $\log I_1$. Except, of course, for the overlap regions where interaction is apparent. For obvious reasons, and at the fovea as well, the slope constants of these functions, showing a collective consistency, provide estimates of the capacity of a particular kind of light to exhaust excitability by another kind of light. These estimates are (for 'monochromatic' lights) free from complications by ocular absorptions irrelevant to the excitation process. Such data are fundamental for visual theory.

Brief reference is all that can be made here to the important fact that the tripartite character of the excitability contour in retinal periphery is preserved and made even more striking by prolonging the exposure-time of the test-light. The data thus far cited have involved an exposure-time of ca. 0.04 sec., with the breathing of air. An example is here given of what happens when a longer exposure-time is employed. Again $\sigma_{\log \Delta I}$ (always) goes through its multiple changes. For these changes a simple explanation is possible, but is outside the scope of this note.

Similarly, the duplex nature of the scotopic function is preserved and enhanced when the partial pressure of O_2 inhaled is changed. The details of these effects, which are also a function of test-light exposure, require separate discussion.

I suggest that these general phenomena, as well as those connected with the form of the test-target (3), require consideration with respect to "mesopic" thresholds.

V

There are two facets of the present results which seem to justify special, abrupt comment here, —without entering upon quantitative matters, and while paying only a passing bow to the problem (psychological?) of the actual nature of the 'incremental threshold' experience. The first concerns the general problem of evaluating "cone" threshold intensities for retinal periphery. For a variety of reasons, of cogency easily demonstrated, it is necessary to employ the 50 per cent frequency of response (τ') as index of excitability. The basic reason concerns the properties of $\sigma_{\log \Delta I}$ as given by $\psi(S)$. But, in the past, estimates of "peripheral cone thresholds" have been made, fragmentarily, by way of 'breaks' in dark-adaptation contours and the like, from 'limits' procedures or modifications thereof; these are demonstrably confused by the now ascertained properties of the probability of seeing as function of λ of test-light. Or, more elaborately, by noting the intensities at which "color" is reported.

It is a fact that in the several varieties of the incremental threshold process, including that in which the background intensity is zero, the proper color, according to the λ, may appear either far below the chief 'break,' or well above it. Such color-based estimates of "cone" thresholds are in all likelihood spurious.

On the other hand, incremental threshold data via $\psi(S)$ at retinal periphery provide (a) unambiguous estimates of photopic threshold intensities; (b) evaluations of their properties under diverse circumstances; (c) relations of these to impressions of color.

VI

I wish to cite here, very briefly and without adequate development of consequences, a contribution of the incremental threshold process to a still altogether too confused matter. I refer to the question of "photosensitization" through the action of red light. In certain essential respects this has been reviewed by Dr. Miles (10), and I need go no further into that. Essentially, however, there persists in some quarters an historical confusion. At bottom it derives from the assertion that "red" light, comparatively speaking, "does not act on retinal rods." From this notion, derived from incomplete and imperfectly apprehended "threshold" intensity data across retinal meridians, a body of incorrect "practical" conclusions has flowed.

There is illustrated a sample of the data—an entirely fair sample—of the 'adapting-out' efficiency of a specific red light of narrow λ-span, for a red and for a white test-target. There is no photosensitization. And it is quite obvious, I think, that statements or implications that "red" light does not affect "rods," or scotopic function, are silly and out of court. I am aware of suggestions to the effect that, for example, dark-adaptation after exposure to "red" light is speedier than one might anticipate; these ideas also are incorrect.

It may be that there are involved here not only misleading effects of experimental techniques, but also a particular confusion of units in which the thinking about some immediately connected problems has indulged.

The matter of technique concerns, again, the properties of $\sigma_{\log \Delta I}$; it is uniformly demonstrated that, whatever the λ of adapting light, and whatever the λ-composition of test-light, a low-intensity adapting light reduces $\sigma_{\log \Delta I}$. This means inevitably that a "threshold"-examination procedure which implicitly relies upon a process involving a high probability of seeing will result in a spuriously "lower" threshold when a low background

is present. Stiles' (5) difficulties are involved here (in reverse); I may in the past have been partly entrapped by it myself.

The second point concerns units of intensity. It is becoming increasingly clear, I think, that one must be concerned about two things in this matter of visual excitation, perhaps especially for retinal periphery: (i) energy, and λ-specificity as concerns (ii) brightness. Elaborations are obvious. With regard to the problem of effect of "red" light, units of each type require consideration. It has been suggested that the 'incremental threshold' process, properly used, has peculiar advantages for such inquiries.

SUMMARY

It is presented that, on the basis of seeing-frequency data involving 'incremental intensity thresholds' by way of seeing-frequency data as function of level of light-adaptation, the scotopic ("rod") excitability function is actually duplex. Several related matters are discussed, with specific reference to the problem of peripheral 'cone' thresholds; and to the actions of "red" light.

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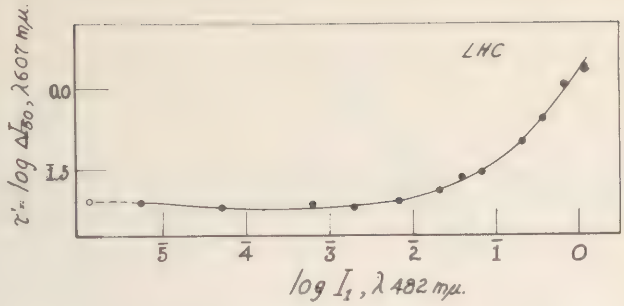

Figure 1. Incremental intensity thresholds, at fovea, $+\Delta \underline{I}$ for 50 per cent seeing of $\lambda 607$, $0^{\circ}.5$ square on an adapting background of $\underline{I}_1$, $\lambda 482_{m\mu}$ (15° square); LHC ; left eye; $t_{exp.} = 0.04$ sec.. At the left (open circlet) is the value with $\underline{I}_1 = 0$. Slight photosensitization.

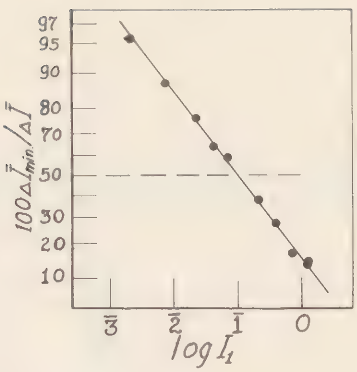

Figure 2. The data of Figure 1, displayed as $1/\Delta I_{50}$ as per cent of $1/\Delta \underline{I}_{50 min.}$, on a probability grid. The inverse slope ($\sigma_{\log I_1}$) gives an uncomplicated measure of the capacity of $\lambda 482$ to adapt-out sensitivity to $\lambda 607$ under the conditions.

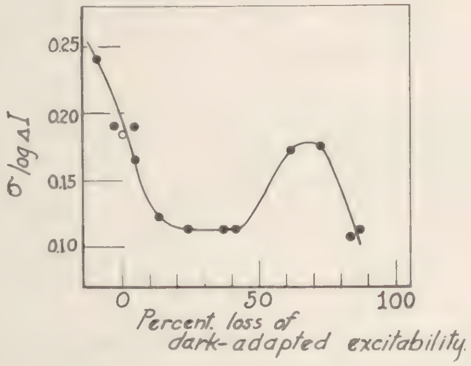

Figure 3. The behavior of $\sigma_{\log \Delta I}$, in the ψ (S) functions giving $\log \Delta \bar{I}_{50}$ in Figure 1. Note the rise of σ at the level of $\underline{I}_1$ leading to just above 50 per cent loss of maximum excitability for the $\Delta \underline{I} \lambda$.

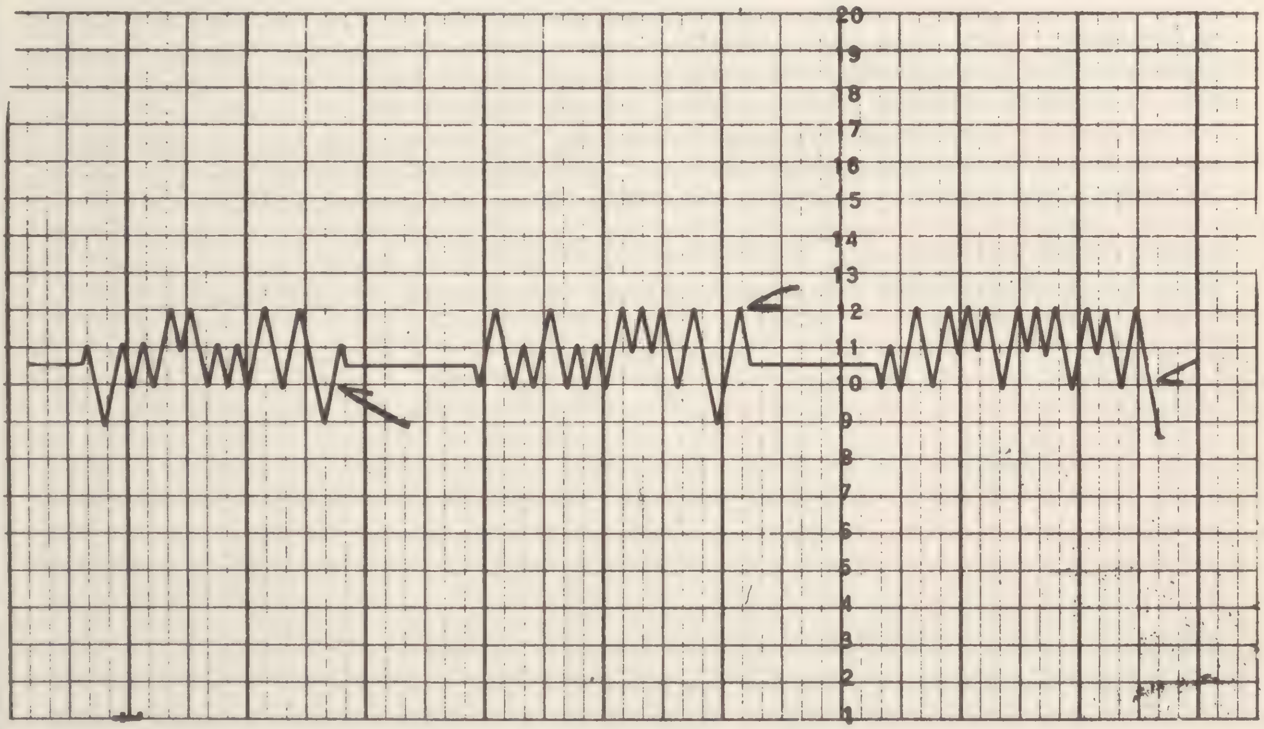

Figure 4. A randomly picked record of visual responses "seen," and not seen, on the Dyon-Mood procedure.

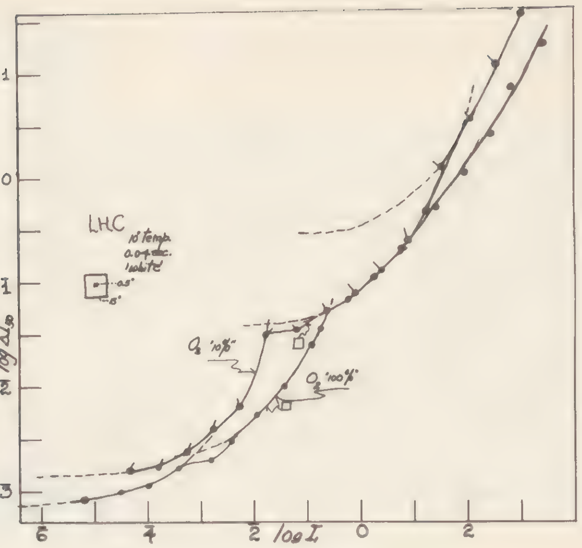

Figure 5. Incremental threshold data (ΔI_{50}), left eye of LHC, white light in light-adapting field and in test patch (0°.5°), 15° temporal, with 2 levels of O_2 intake. (Thresholds for complete margins of the background are indicated.)

Discussion:

Dr. Blackwell commented that he was greatly interested in Dr. Crozier's theoretical notion that there might be two kinds of rod systems. Dr. Blackwell then reported data recently collected in his laboratory which suggest that the cone systems change their characteristics as a function of luminance level. The evidence for this comes from studies of what might be called the summation function, at different intensity levels in the fovea. Data reported at the 31st meeting of the Committee "Foveal detection thresholds for various durations of target presentation" can be used to show that, when working in the pure rod-free area, as one reduces the luminance level there is an increase in the effective summation function, represented by the fact that Ricco's law applies to increasingly large stimuli. This may mean that, as one goes to lower luminances, more diffuse neural-connecting systems become effective.

Dr. Crozier stated that he had no objection to Dr. Blackwell's theory, but could only comment that he had not himself encountered any data pointing in that direction.

A BIBLIOGRAPHY ON DARK ADAPTATION

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PREFACE

The present bibliography was compiled as a necessary first step to experimental work at Tufts College upon an Air Force research project [AF 30(602)-199] sponsored by the Human Factors Office, Griffiss Air Force Base, with Dr. R. J. Christman as Project Engineer and Dr. J. W. Wulfeck as Project Director. The research is designed to investigate the influence of brief durations and low intensities of the preceding light upon the course of the subsequent dark adaptation. As the literature was searched specifically for experiments dealing with these two variables of white light, it soon became clear that a more comprehensive coverage might be of value to other workers in the field.

Joseph W. Wulfeck

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January, 1953

A BIBLIOGRAPHY ON DARK ADAPTATION

INTRODUCTION

During the past twenty years probably no aspect of vision has deserved or received more attention than night vision and dark adaptation. In response to the demands of two wars, biochemical and electrophysiological research have received increased support. The requirement that specified levels of dark adaptation be maintained, the need for finding an alternative for total darkness in becoming dark adapted, and the hope of speeding up dark adaptation have resulted in widespread efforts to identify and establish the ranges of the variables affecting the instantaneous threshold and the subsequent course of dark adaptation. In addition, numerous night vision testers have been developed and masses of normative, validity, and reliability data have been accumulated.

The literature on the biochemistry and electrophysiology of dark adaptation is burdensome, but the individual researcher can find his way through most of it in a reasonable period of time.*

Within the last four years an Annotated bibliography on visual performance at low photopic illumination level has been prepared by Rock (324). The research on development, validity, and reliability of night vision testers has been summarized in a comprehensive report by Berry (30).

Reviews by Adams (3) in 1929 and by Lythgoe (261) in 1940 have emphasized the mechanisms and theory of dark adaptation, but the literature dealing specifically with the experimental data of dark adaptation, especially as related to its associated variables and their ranges, has grown more and more extensive and scattered. The present bibliography brings together a number of such references in an effort to make these experimental data more easily accessible. Although such an undertaking is so large that it is dangerous to claim completeness for it, it is hoped that few references of importance have been overlooked.

While this bibliography includes items relating dark adaptation to many variables, its basic concern is with the effects of pre-exposure variables. The heaviest emphasis is on the effects of the duration and the intensity of the preceding light, and the relation between them. There will also be found a fair sampling of references on the effect of wave length of the preceding light, but completeness is not claimed.

In addition to material on the effects of intensity, duration, and wave length, literature from the following areas is included:

1. Theoretical material on the course of dark adaptation, providing it is based on specific experimental evidence. No effort has been made to include speculations founded on generalized curves borrowed from other sources.

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*If the investigator is aware of the work, for example, of Broda, Chase, Dartnall, v. Euler, Goodeve, Granit, Hecht, Hosoya, Krause, Lythgoe, v. Studnitz, Tansley, Wald, Zewi, and possibly a very few others, he can gather almost all that is known of the biochemistry of dark adaptation; if he knows of the work of Crescitelli, Granit, Hartline, Jahn, and Riggs, almost all that is known of the electrophysiology of dark adaptation is available to him.

2. Characteristics of the subject that have been found to play a role in adaptation: the effects of age, drugs, fatigue, muscular activity, inter-sensory stimulation, etc.

3. Methodological studies, e. g., comparisons of various measures of sensitivity, effect of various psychophysical procedures, effect of retinal area, effect of size and brightness of test patch surround, etc.

Not included are:

1. Descriptions of apparatus used for measuring dark adaptation, particularly when a clinical or night vision testing application was contemplated and especially when no experimental data were cited.

2. Numerous studies of a strictly technological nature, e. g., spectrophotometric specification of filters for red goggles, etc.

3. Studies of the photochemistry and electrophysiology of dark adaptation.

This bibliography is, therefore, a selective list; there will undoubtedly be some disagreement as to the relevance of some of the titles included or omitted.

Among the sources used were Psychological abstracts, Psychological index, Journal of the Optical Society of America, Helmholtz's Physiological optics, Murchison's Handbook of general experimental psychology, Stevens' Handbook of experimental psychology, Boring's Sensation and perception in the history of psychology, Titchener's Experimental psychology, Troland's Psychophysiology, Vol. II, Walls' The vertebrate eye, Duke-Elder's Textbook of ophthalmology, Fulton et al. Bibliography of visual literature and its supplements, Berry's Review of wartime studies of dark adaptation, Polyak's The retina, Granit's The sensory mechanisms of the retina, the bibliography based upon Frank K. Moss' card catalogue, William J. Crozier's card catalogue, Tufts College Handbook of human engineering data and the card indices assembled for it, etc. In addition, Dr. William Verplanck and Mr. Richard Mitchell of Harvard University very kindly permitted the use of 150 or more titles from a bibliography they had already started in this area for the Armed Forces-National Research Council Vision Committee. These titles are marked with an asterisk in the present bibliography.

Although Adams' report on Dark adaptation (3) was used, so many of her references proved to be erroneous that they are not cited unless verified either from the original or from some other secondary source. It is hoped that those remaining may be checked and included at a later date.

The method of citing references is taken from the Psychological abstracts. For citations of service reports, notoriously difficult, the form used by the Tufts College Handbook of human engineering data has been copied. It is hoped that sufficient information is given so that there can be no doubt as to the service responsible for a study, its date, and any other information that will make it easy to locate. In a few cases it was impossible to determine all the information completely, but the report seemed significant enough to call for citation even in the incomplete form. In a few cases no date is given; these are marked "n. d." in the place where the date usually appears. Following the practice of the Abstracts articles in foreign languages are given their title in the language in which the article appears, except for those in Japanese and in the Slavic languages. Here the translated title is given, but it is placed in parentheses. The title of the periodical is usually an adequate cue to the language, but where it is not, the original language is named.

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Brightness of the Atmosphere; Effects of Cloud Conditions
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Bethesda, Maryland
20 October 1953 Vol. II, pp. 1011-1116

"This report represents data on atmospheric brightness taken at 17 selected altitudes from 1,000 to 35,000 feet to demonstrate the effects of various types of cloud conditions. Tables give the measured brightness of the zenith, the nadir, and of points separated by 15 degrees of arc on circles at zenith angles 30°, 70°, 85°, 110°, and 150°. Data on time, geographical position, pressure, air temperature, dew point, altitude of observation, sun's azimuth, sun's altitude, and the various cloud conditions are included in the tables. Curves are included which show the relationship of measured brightness to pressure, scattering angle, and bearing. Curves based on the Hulbert theory are included for comparison purposes. A series of photographs taken at each altitude below, through, and just above the level of the cloud formation existing on one day are included for visual comparison with the curves.

"The data indicate the extent and nature of the variability of atmospheric brightness below cloud formations and the similarity between clear weather sky brightness previously reported and the sky brightness above cloud overcasts.

"Pseudo-adiabatic diagrams are included for comparison with the brightness data to show the relationship between sky brightness and temperature and moisture lapse rates. The data demonstrate a rapid decrease in atmospheric brightness as one ascends towards the base of a cloud layer. The cloud levels correspond to the levels of the temperature inversions or changes in the temperature lapse rate in the direction dry to wet. The data previously reported show the opposite effect for clear weather wherein atmospheric brightness is increased at the level of the temperature inversion. In addition the overcast reverses the clear weather sky brightness progression from the lowest values near the zenith to the highest values near the horizon. In other words, above cloud layers the brightest portion of the sky is near the zenith rather than at the horizon as found on clear days and above cloud layers."

Masking of Cathode Ray Tube Displays by Ambient Illumination
Adler, Helmut E., Kuhns, Margaret P., Brown, John L.
Columbia University
Aero Medical Laboratory, WADC
November 1953 20 pp.

"Masking thresholds of ambient illumination were obtained for a signal presented as a horizontal trace on a cathode ray tube. Seven trace luminances and two trace widths were used. Ambient illumination was measured in terms of the luminance superimposed on the surface of the tube. The results show that in radar operation ambient light can be present considerably in excess of the signal strength without masking the signal display, except when the signal luminance is below 0.1 ml. If the signal strength is increased by a small amount, the masking threshold fro ambient light rises rapidly at first, but at a decreasing rate, and eventually reaches a point where further increases in trace luminance

do not result in a further increase in masking threshold. Above this level of ambient light (somewhat higher than 1000 ml. in this experiment) no increase in signal strength can compensate for the masking effects of the ambient light.

"Increasing the dimensions of the trace, while holding trace luminance constant, appears to afford tolerance for somewhat more ambient light."

The Effect of Red Light on the Absolute Visual Threshold
McLaughlin, Lt. Samuel C.
Project No. NM 001 059.28.02
U.S. Naval School of Aviation Medicine
Naval Air Station, Pensacola, Florida
3 August 1953 7 pp.

SUMMARY: "An hypothesis is advanced which may account for the appearance or non-appearance of red-light photosensitization in closely similar experimental situations in terms of the psychophysical method of threshold determination which is employed. This hypothesis, if valid, explains the appearance in the literature on vision of several sets of conflicting data during the past ten years. Data are presented in support of this hypothesis, and these data appear to demonstrate, independently of the validity of the subject hypothesis, that the red-light photosensitization phenomenon previously reported from this laboratory should be regarded as nonexistent for purposes of operational application."

Correction Factor to the Photometric Square Law for Area of Source and Receiver
von Schelling, Hermann
Medical Research Laboratory Report No. 231
Bureau of Medicine & Surgery, U.S. Navy Dept.
27 July 1953 8 pp.

"The photometric square law is correct only for point sources of illumination and for point receivers. These assumptions are not met rigorously under laboratory conditions. Photometric readings may be biased. A chart and a table are presented to correct the readings for area of source and receiver. The underlying formulae are given and detailed directions are added for applying the chart and the table."

Three Charts for Measuring Chromaticity Shifts Resulting from Changes in Illumination, Macular Pigmentation, and Intraocular Absorption
von Schelling, Hermann
Medical Research Laboratory Report No. 210
Bureau of Medicine & Surgery, Navy Dept.
14 October 1952 12 pp.

"It is recognized that spectral reflectances must be calculated for the determination of exact shifts in chromaticity due to changes in illumination or to variation between observers in the matter of macular pigmentation and intraocular absorption. However, three charts are presented which greatly facilitate the determination of the average shift from the respective values of the 1931 Standard Observer and Coordinate System of the International Commission on Illumination. Comparison of results from the two methods of determining these shifts shows a variation in results not exceeding .025 and usually smaller than .010.

"Directions are given for the use of these charts, which greatly simplify the process of calculation and shorten the time involved. Average shifts have been plotted for the change from Illuminant A to Illuminant C, and for a variety of macular pigmentations and intraocular absorptions. A variety of sample problems are demonstrated, and other applications are outlined."

Perception of Contour: I. Introduction
Ludvigh, Elek—Director, Kresge Eye Institute
U.S. Naval School of Aviation Medicine (Rep. No. NM 001 075.01.05)
Naval Air Station
Pensacola, Florida
17 August 1953 9 pp.

SUMMARY: "Experimental evidence is presented which is interpreted as showing that the higher derivatives of energy with respect to distance on the retina are the main effective stimulus to contour formation and are the feature of the physical world which chiefly carries visual 'intelligence.' An extensive field of investigation would appear to be available."

Perception of Contour: II. Effect of Rate of Change of Retinal Intensity Gradient
Report No. NM 001 075.01.05
Ludvigh, Elek—Director, Kresge Eye Institute
U.S. Naval School of Aviation Medicine
Naval Air Station, Pensacola, Florida
17 August 1953 5 pp.

SUMMARY: "The present investigation continues the effort to ascertain the nature of the retinal stimulus effective in producing the perception of an edge under certain simple conditions of photopic foveal vision.

"A method is briefly described by means of which a distal stimulus is computed which, under the conditions of observation existing, will result in the desired proximal or retinal stimulus. The observer can project a small fiducial dot of light onto the distal stimulus to indicate where an edge, break, contour or discontinuity appears.

"It is shown that the subjective apparent intensity or brightness is not simply related to the intensity on the retina and, indeed, that the relationship may be inverse, namely, that intensely illuminated regions of the retina may appear dark while adjacent, less intensely illuminated regions may appear bright. It is shown that if one were to attempt to express this phenomenon in terms of the classical concept of the Weber-Fechner fraction, $\Delta I/I$, it would result in a positive intensity gradient producing a negative brightness increment.

"It is further shown that the amount of energy decrement on the retina has little effect upon the appearance of an edge. It is then shown that the rate of change of energy with respect to retinal distance is an unimportant factor in the production of edges and that the lowest derivative of energy with respect to retinal distance of substantial significance for contour formation is the second derivative.

"A fundamental principle is stated to be that a doublet edge may appear substantially symmetrically distributed on either side of a point where the rate of change of the rate of change of intensity on the retina is maximal. The separation of this doublet edge will be smaller the greater the value of the fourth derivative of energy with respect to retinal distance.

"The phenomena of contour formation, simultaneous contrast, absolute photopic threshold or light sense, differential photopic threshold or light difference sense, minimum visible or visual acuity for a line and minimum resolvable or minimum separable or visual acuity may all be considered chiefly in terms of the second and higher derivatives of energy with respect to retinal distance."

Factors Affecting Differences in Apparent Size Between Opposite Halves of a Visual Meridian
Brown, Kenneth T.
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 53-253
August 1953 pp. 464-472

"A difference in apparent size between opposite halves of the same visual meridian may be called a half-meridional difference (HMD). The HMD's have been measured in six subjects for both the horizontal and vertical meridians, using the right eye, left eye, and both eyes. All six kinds of measurements were made on each subject for periods of from two to nine weeks.

"Significant differences were found between the HMD's of the left and right eyes in both meridians. Thus an ocular factor contributes to HMD's. This factor appears to be different visual angles for corresponding retinal points. Trends were sometimes found with respect to time, so there is also an unstable factor in the visual system which contributes to HMD's. This factor varies independently along the horizontal and vertical meridians. With a given meridian, however, the HMD's of the left and right eyes vary concomitantly. Thus the unstable factor is common to the two eyes and is probably located in the visual cortex. Since trends were found, apparent size in a given part of the visual field sometimes varies gradually but markedly with respect to time. This means that for a given locus of retinal stimulation the subjective directional value relative to a foveal stimulus varies in a similar manner with respect to time. Thus topological transformations of subjective directional values have been found to occur.

"HMD's produced by the ocular factor appear relatively stable and usually small, whereas the HMD's of the left and right eyes are modulated concomitantly by the unstable factor, which sometimes causes large HMD's. These findings indicate that the relation between visual angles for a pair of corresponding retinal points is relatively stable, but the subjective directional values of both members of the pair with respect to a foveal stimulus sometimes vary markedly and concomitantly as a function of time."

Investigation of Atmospheric Refraction at Low Altitudes
Strand, Kaj G.
Arctic, Desert, Tropic Information Center
Air University
Maxwell Air Force Base, Alabama
February 1953 36 pp.

"In the fall of 1949, the Arctic, Desert, Tropic Information Center was asked by the Air War College to make a critical survey of methods of predicting illumination data for Arctic air operations. This survey brought out that one of the factors limiting the accuracy of all available methods of predicting illumination conditions in the Arctic is a lack of reliable data on atmospheric refraction at low angular altitudes. Since atmospheric refraction makes a celestial body appear higher in the sky than it actually is, refraction delays the time of sunset, advances the time of sunrise, and extends the duration of both morning and evening twilight.

"All sources of illumination information reviewed in this survey used the so-called 'standard values' for refraction, which are computed for an 'ideal' atmosphere, with no concessions made to the actual atmospheric structure. Illumination predictions made by using these standard values are innaccurate whenever the actual value of the refraction varies from the standard. This inaccuracy is relatively minor in the low and middle latitudes, but can be quite serious in the Arctic, where the sun rises and sets very slowly.

"Most authorities agree that the refraction tables now in use are not accurate under all atmospheric conditions. However, the amount of error in the tables has been the subject of much argument. Naked-eye observations using hand held sextants have indicated that large errors exist. Critics of these studies question the accuracy of the observational procedures used and maintain that existing refraction tables have only small errors. (See A. Fletcher 'Astronomical Refraction at Low Altitudes' in Journal of the Institute of Navigation, Volume V, Number 4, October 1952, for a comprehensive review of this controversy.) To provide data by which this problem can be resolved and from which a new refraction theory can be derived if necessary, the Research Studies Institute, Air University, contracted with Northwestern University to make precise measurements of refraction by photography. The following paper, by Dr. Kaj Strand, Director of the Dearborn Observatory, is the final report on this contract (Contract No. AF 01(600)-2).

"From his observations, Dr. Strand concludes that the presently accepted refraction tables and the theory on which they were computed are basically correct but that the correction tables for specific atmospheric conditions should be revised. More important than any conclusions which can be drawn from the study itself however is the fact that Dr. Strand's work has produced accurate data by which all refraction theories can be evaluated.

"While the refraction values determined by this study cannot be used directly in the Arctic, they do provide a reference from which refraction values for Arctic conditions can be derived. They also provide a yardstick with which to determine the accuracy of less precise observations made in the field. This study does not answer the entire problem of predicting Arctic illumination but it does bring the problem a long step nearer solution."

Factors in Night Vision Sensitivity: III. The Interrelation of Size, Brightness and Location
deGroot, Sybil G., Dodge, Jane M., and Smith, JoAnn
Medical Research Laboratory Report No. 234
Bureau of Medicine & Surgery, Navy Dept.
14 September 1953 13 pp.

"The interrelation of size, brightness and location of a stimulus of extended duration was measured at the minimal scotopic sensitivity of the eye. Limens were determined at four distances from fixation on four radii, up, down, nasal and temporal, with brightnesses between 25 muL and 125 muL and sizes between eight and twenty-five minutes visual angle diameter.

"Size-brightness relation changes with distance from fixation in all directions. Scotopic sensitivity depends upon and must be expressed in terms of the three parameters--size, brightness and location in the visual field."

The Influence of Methodology on Research on Instrument Displays
Senders, Virginia L., and Cohen, Jerome
Antioch College
Wright Air Development Center
WADC Technical Report 53-93
April 1953 32 pp.

"The methods used in sixty-one studies of visual displays were analyzed and the results summarized in tabular form. Ih characteristic experiments subjects have been presented tachistoscopic exposures of single instruments and performance has been measured in terms of exposure time and errors.

"In planning research on visual displays, we must have some knowledge of what constitutes a good display. Nineteen criteria of the 'good panel' are derived, few of which

have been studied experimentally. The basic process underlying instrument use is checking the instrument presentation against the subjective probability distribution of the possible indications. The rectangular distribution of settings used in most experiments may yield distorted results because such distributions may seldom occur in practice.

"Future research must include: 1) studies to solve immediate design problems; 2) studies of basic design variables in situations of high face-validity; and 3) studies of the fundamental psychological processes by which information is obtained from instruments."

<u>A Study of Night Myopia</u>
O'Brien, Brian
University of Rochester
Wright Air Development Center
WADC Technical Report 53-206
May 1953 23 pp.

"The literature on night myopia is reviewed in some detail, and a critical evaluation of certain outstanding papers is undertaken. There is general agreement upon the effect of chromatic aberration and the Purkinje shift, but disagreement on the importance of spherical aberration and involuntary accommodation in producing the myopia.

"The progressive influence of spherical aberration combined with a retina which loses resolution with diminishing illumination is considered, and appears to explain myopia at the lower limits of rod vision.

"Two sets of experiments are described in which vision is restricted to cone vision thus eliminating the Purkinje shift. In one set both natural and ring aperture pupils distinguish between spherical aberration and involuntary accommodation. In the other a ballistic flash technique prevents any accommodation after the test target is displayed.

"It is concluded that both spherical aberration and involuntary accommodation are significant in night myopia as ordinarily observed."

<u>A Study of the Mechanism of Visual Acuity in the Central Retina</u>
University of Rochester
Wright Air Development Center
WADC Technical Report 53-198
May 1953 54 pp.

"Measurements of transverse sections of human retinas provide precise cone-spacing data from center to edge of fovea. Measurements with an electric-wave model confirm the mechanism concentrating and isolating light by each cone, which thus serves as an isolated receptor. Correlation of these histological data with measured acuity shows cone spacing and reciprocal acuity varying together from center to edge of the fovea.

"Measurements with a new ballistic-flash technique of cone thresholds, of eye movements, and of double-star acuity show high uniformity of thresholds among foveal cones, in disagreement with the Hecht theory. No significant effect of involuntary eye movements is found, and acuity for double stars proves substantially independent from illumination level.

"High and reproducible accuracy of fixation is demonstrated by a new technique utilizing local areas of tilted cones as retinal landmarks. Removal of optical aberrations by an interference method shows that retinal structure and not the optical system sets the final limit on acuity."

The Coding of Aircraft Controls
Hunt, Darwin P.
Aero Medical Laboratory
Wright Air Development Center
WADC Technical Report 53-221
August 1953 26 pp.

"This report summarizes the available information concerning several techniques of control coding which seem to be of value to the design engineers. Control coding means providing the operator with a way of identifying the controls. Five methods of control coding are discussed: Shape coding, size coding, location coding, color coding, and mode-of-operation coding. Information is given concerning each coding technique so that the design engineer can apply any of these methods as the need arises. Many of the advantages and disadvantages of each method are pointed out. The question of when to code and the type of coding to use are discussed."

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